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Abstracts of Papers Published by the Staff of the Great Lakes Laboratory for Fisheries and Aquatic Sciences 1968-1986

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CANADIAN TECHNICAL REPORT OF FISHERIES
AND AQUATIC SCIENCES. NO 1634

August 1988

ABSTRACTS OF PAPERS PUBLISHED BY THE STAFF OF THE GREAT LAKES LABORATORY FOR FISHERIES AND AQUATIC SCIENCES,

1968-1986.

Compiled by

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ABSTRACT

NICHOLSON, H.F. 1988. Abstracts of papers published by the staff of the Great Lakes Laboratory for Fisheries and Aquatic Sciences, 1968-1986. Can.Techn.Rept.Fish.Aquat.Sci., (1634). pp.i-iii, 1-157.

This report lists references to the 411 scientific papers published by past and present staff of the Great Lakes Fisheries Research Branch of the Canada Department of Fisheries and Oceans over the period 1968-1986. For the most part, abstracts are included, but where these are not available, conclusions, summaries and extracts are utilized.

RESUME

NICHOLSON, H.F. 1988. Abstracts of papers published by the staff of the Great Lakes Laboratory for Fisheries and Aquatic Sciences, 1968-1986. Can.Techn.Rept.Fish.Aquat.Sci., (1634). pp.i-iii, 1-157.

Ce rapport énumère les références de 411 documents scientifiques publiés par le personnel antérieur et actuel de la Direction de la recherche sur les pêches des Grands Lacs, du ministère des Pêches et des Océans du Canada, pour la période 1968-1986. En grande partie, les résumés sont inclus. Toutefois, en l'absence de résumés, on utilise des conclusions, des sommaires et des extraits.

PUBLICATIONS 1968-1986

BARTON, D.R.(under contract)

1986 - Benthic fauna from Great Lakes Institute cruises on Lake Huron and Georgian Bay 1963 and 1964. Can.Techn.Rept.Fish.Aquat.Sci., (1487).

Data from several cruises on Lake Huron and Georgian Bay collected by the Great Lakes Institute (University of Toronto) during 1963 and 1964 were examined. Counts of the major groups of organisms recorded on index cards by the original collectors were compared to the contents of the preserved samples. No discrepancies were detected for the Amphipoda and Mollusca, but about 5 percent of the card and sample counts for the Oligochaeta and Chironomidae differed substantially. The distribution of animals by depth and region were consistent when the data from monthly cruises were treated as replicates to calculate yearly station means. Only Pontporeia was common enough to detect seasonal trends, increasing in May through July, then declining.

Most invertebrate groups were most abundant at depths between 20-50 m. Chironomids other than Heterotrissocladius oliveri were more common nearshore, at depths less than 30 m. Mean abundance and spatial distributions of benthic animals were similar to those reported from other surveys on Lake Huron, but larger numbers of organisms were collected at depths between 20-50 m on the G.L.I. cruises. Standing stocks were much lower in Georgian Bay, especially in the western part of the basin.

BLACK, G.A.P.

1976 - with HINTON, D.J., JOHNSTON, H.C., & SPRAGUE, J.B.(under contract). Annotated list of copper concentrations found harmful to aquatic organisms. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (603).

A summary is presented, of 101 selected papers, which relate concentrations of copper in water, to deleterious effects on aquatic organisms. Tables containing 169 items are arranged by increasing concentrations, for various species and groups of organisms. Listed concentrations range from 0.01 to 63,500 µg/l. Some findings on toxicities of various forms of copper in water are listed. References and abstracts are given.

BORGMANN, U.

1977 - Electron transport system activity in Daphnia and crayfish. Can.J.Zool., 55:847-854.

The activity of the electron transport system (ETS) in Daphnia magna and the crayfish Orconectes propinquus was estimated by measuring NADH-, succinate-, and NADPH-cytochrome c reductase. The activity of the total ETS was also measured by following NADH oxidation, and by measuring the rate of cytochrome c reduction upon addition of cyanide after a steady state between cytochrome c reductase (EC 1.6.99.3) and cytochrome oxidase (EC 1.9.3.1) had been reached. ETS activity is highest in crayfish gill when NADH or succinate is used as substrate, and highest in crayfish hepatopancreas when NADPH is

BORGMANN, U.(cont.)

used. Michaelis-Menten constants for NADH, NADPH, and cytochrome c are comparable with some of the lower values reported for mammalian systems. The usefulness of the ETS assay in the study of toxic substances is discussed.

1978 - The effect of temperature and body size on electron transport system activity in freshwater zooplankton. Can.J.Zool., 56:634-642.

Electron transport system (ETS) activity in *Mysis relicta*, *Limnocalanus macrurus*, and surface zooplankton was measured by following the rate of reduction of cytochrome *c* in the presence of NADH, succinate, the rate of reduction of cytochrome c in the presence of NADH, or NADPH. The steady-state kinetics indicate that NADPH is oxidized by a different ETS from NADH and succinate, and more than one system may exist for the oxidation of NADH and succinate in surface zooplankton. The NADPH requiring ETS which, because of its higher K_m, presumably does not reduce cytochrome *c* *in vivo*, is probably equivalent to the microsomal NADPH requiring ETS from vertebrates and insects used in the detoxification of organic compounds. ETS activity is affected by both environmental temperature and size of the organism, with environmental temperature affecting both the total activity of the enthalpy of activation of the system. Larger organisms have a lower activity per unit weight compared with smaller animals. Because the effects of temperature and size are roughly similar for NADPH oxidation and NADH or succinate oxidation, the ratio of NADPH to either NADH or succinate oxidation may be a useful indicator of exposure to toxic organic compounds.

1978 - with KRAMAR, O., & LOVERIDGE, C. Rates of mortality, growth, and biomass production of *Lymnaea palustris* during chronic exposure to lead. J.Fish.Res.Bd.Can., 35:1109-1115.

Lymnaea palustris, a freshwater snail, was exposed to lead in a continuous-flow system from newly laid eggs until reproductive maturity. Lead, at concentrations as low as 19 $\mu g.l^{-1}$, caused a significant increase in the mortality rate, although the growth rate was not affected. The lead-induced mortality was proportional to the lead concentration raised to the exponent 2.5. The analysis of mortality as a rate function was found superior to the use of the more conventional LC50 (concentration resulting in 50 percent mortality). A plot of the logarithm of the lead-induced mortality against log lead concentration is linear and has the same slope as plots of double logarithms of the inverse survival at any one time versus log lead concentration or log time versus log LC50 or log LT50 (time to 50 percent mortality) versus log lead concentration. The mortality rate, unlike the percent mortality, is independant of time and can be combined directly with the growth rate to estimate the biomass production rate. A 50 percent drop in the rate of biomass production was observed at 36 $\mu g.l^{-1}$ and a drop to zero production at 48 $\mu g.l^{-1}$. Lead uptake in whole snails was found to be proportional to the lead concentration in the water, giving a concentration factor of 8500 on a dry weight basis.

BORGMANN, U.(cont.)

1979 - with LOVERIDGE, C., & COVE, R. A rapid method for the estimation of, and some factors affecting, copepod production rates in the Burlington Canal. J.Fish.Res.Bd.Can., 36:1256-1264.

A method is described for estimating in situ biomass production rates of copepods. The youngest naupliar stages are isolated by filtration through two different size sieves, and growth is measured after laboratory incubation by filtering through a series of eight filters. Since the filters appear to be relatively efficient at separating copepods of different sizes, copepod size can be estimated from the pore size of the filters alone, resulting in a very rapid procedure for calculating biomass. This method allows experimental manipulation of environmental conditions, permitting for example, an estimation of the relative importance of temperature and food abundance in the seasonal growth cycles of these organisms. It was concluded that, in the Burlington Canal, temperature exerts a greater influence on growth rate than does food concentration, although adaptation to food levels may be expressed indirectly, due to a similarity in the seasonal cycles for temperature and food. The method is also useful in predicting the potential impact of toxic substances on copepod production rates under natural conditions.

1979 - Proceedings of the Fifth Annual Aquatic Toxicity Workshop, November 7-9, 1978, Hamilton, Ontario. See under WONG, P.T.S.

1979 - Toxicity of copper to aquatic biota. See under HODSON, P.V.

1980 - Interactive effects of metals in mixtures on biomass production kinetics of freshwater copepods. Can.J.Fish.Aquat.Sci., 37:1295-1302.

The effect of metal mixtures on the biomass production rates of natural assemblages of copepods was predicted by assuming that metal-induced increases in the inverse of the growth rate (i.e., the growth time) are additive. The average observed growth time increase, ΔGT_{obs} in 14 binary mixtures of the metals Cd, Cu, Hg, Pb, Zn, and As was 17 percent larger than the average calculated growth time increase ΔGT_{cal} (assuming additivity), indicating a slight but statistically significant synergism. Synergism in multimetal mixtures appears to be cumulative, since the average ΔGT_{obs} was 53 percent greater than the average ΔGT_{cal} in mixtures containing five metals simultaneously. One of the 15 possible binary mixtures (Zn:As) of the six metals tested demonstrated a large divergence between ΔAGT_{obs} and ΔGT_{cal}. For all other metal mixtures studied, most of the toxicity is accounted for by the summation of non-interactive, single, metal effects.

1980 - with COVE, R., & LOVERIDGE, C. Effect of metals on the biomass production kinetics of freshwater copepods. Can.J.Fish.Aquat.Sci., 37:567-575.

The effects of cadmium, copper, mercury, lead, and arsenic on the growth and mortality rates of a natural assemblage of copepods using natural food and water were determined. A seasonal cycle in toxicity was observed for all the metals except arsenic. Lead toxicity appeared to be related to the ash-free dry weight of the seston, but the reason for the variation in toxicity of cadmium, copper, and mercury remain unknown. The chronic toxicity of some metals differs much less between copepods and daphnids than does acute toxicity. The mathematical relationship between growth and mortality rates and metal concentration is discussed and a technique for calculating a sublethally toxic concentration is described.

1981 - Determination of free metal ion concentrations using bioassays. Can.J.Fish.Aquat.Sci., 38:999-1002.

A procedure was developed by which free metal ion concentrations, toxic to aquatic life, can be calculated by comparing metal toxicity before and after addition of a complexing agent of known complexing capacity. Application of this method suggests that the growth of freshwater copepods is affected at free copper concentrations around 10^{-10} to 10^{-9} mol.L^{-1}. In natural waters, with unidentified ligands of unknown complexing ability, this procedure provides the only method currently available for estimating free metal concentrations at the low levels often causing sublethal toxicity to aquatic organisms.

1982 - Particle-size-conversion efficiency and total animal production in pelagic ecosystems. Can.J.Fish.Aquat.Sci., 39:668-674.

A method is described for defining conversion efficiency in pelagic ecosystems on the basis of particle size, rather than trophic level. This permits calculation of a size-corrected biomass function which can be used to describe total animal production by taking into account biomass losses resulting from carnivorous feeding in multitrophic level systems. This, in turn, permits the determination of potential fish production, for any given size fish, from experimental data on zooplankton production using simple equations. Little knowledge of trophic interactions is required. The potential fish production resulting from microzooplankton production in the Burlington Canal is calculated.

1983 - Metal speciation and toxicity of free metal ions in aquatic biota. In; J.O.NRIAGU(ed.), Aquatic Toxicology:47-69. John Wiley & Sons. ISBN 0-471-88901-6.

1983 - Effect of somatic growth and reproduction on biomass transfer up pelagic food webs as calculated from particle-size-conversion efficiency. Can.J.Fish.Aquat.Sci., 40:2010-2018.

Biomass or energy transfer up pelagic food webs to larger sized organisms is a function of (1) direct trophic level transfer through predation, (2) somatic growth, a process that augments biomass transfer through predation, and (3) reproduction, which impedes biomass transfer by moving biomass down the food web to smaller sizes. By assuming that particle-size-conversion efficiency

BORGMANN, U.(cont.)

(log(food consumed/ biomass produced)/log predator-prey size ratio)) is relatively constant, I derive simple equations to calculate the effect of somatic growth and reproduction on biomass transfer up the food web. This defines the conditions under which somatic growth and reproduction can be ignored and biomass flow can be calculated from predation alone, using a previously developed model. When these conditions are not met, the effect of somatic growth and reproduction can be calculated from data on cohort growth and mortality rates. It is not necessary to identify the food of any species. This eliminates one of the problems often encountered when modeling food webs. I have applied these equations to production of Mysis relicta. If the estimates of Mysis abundance and growth rates are correct, then size-corrected production is about 25 percent greater for this species when somatic growth is accounted for in the calculations. This is because mortality of young Mysis appears to be low and most production occurs during somatic growth and not during reproduction.

1983 - with RALPH, K.M. Complexation and toxicity of copper and the free metal bioassay technique. Wat.Res., 17(11):1697-1703.

The concentrations of free and total copper toxic to Daphnia and guppies were determined in inorganic media with and without addition of various concentrations of ß-alanine, glycine, glutamic acid or Tris. Free copper concentrations were determined using a cupric ion electrode. Stability constants calculated for each of the detected complexes compared favourably with previously published values, with the possible exception of the $Cu(OH)_2$ complex. Free copper concentrations in solutions equally toxic to Daphnia were observed to vary greatly, primarily because of the toxicity of copper/amimo acid complexes to this organism. The copper/amino acids were, nevertheless, less toxic than the free copper ions. The copper/ß-alanine complex was observed to be less toxic to guppies than to Daphnia, indicating a difference in sensitivity to different copper complexes in different organisms. Copper/Tris complexes were found to be only slightly toxic to both Daphnia and guppies. A bioassay technique for determining free copper concentrations by comparing copper toxicity before and after addition of Tris was tested and verified. Although free metal concentrations can be determined from properly conducted bioassays, the variation in free metal concentration in equally toxic solutions demonstrates that free metal concentrations cannot be calculated by simply comparing metal toxicity in a test solution with toxicity of the same metal in a standard solution with known free metal concentration, unless it is known that no complexes are present in the test solution which can form toxic complexes with the metal.

1983 - with WHITTLE, D.M. Particle-size-conversion efficiency and contaminant concentrations in Lake Ontario biota. Can.J.Fish. Aquat.Sci., 40:328-336.

The particle-size-conversion efficiency (log food consumption/production divided by log predator-prey size ratio) is shown to be directly related to the relationship between the

BORGMANN, U.(cont.)

concentration of persistent contaminants accumulated primarily through the food chain and body size for organisms in pelagic ecosystems. The difference between particle-size-conversion efficiency for biomass and that for the contaminant gives the slope of the relationship between log contaminant concentration and log body size. This provides a useful theoretical framework for analyzing contaminant concentrations in aquatic biota without the need for specifying trophic level but still incorporating the idea of food chain accumulation. Concentrations of PCB, DDT, and mercury were examined in aquatic organisms from Lake Ontario, ranging in size from zooplankton to large salmonids (a 10^8-fold range in dry weight). The slope of the double log plot of concentration versus weight varied from 0.20 to 0.22 for PCB and DDT and was approximately equal to 0.13 for mercury. This indicates that mercury is accumulated less efficiently through the food chain than PCB or DDT. After correcting for incomplete uptake and retention of the contaminant, an estimate of particle-size-conversion efficiency for biomass of about 0.26 was obtained, which agrees reasonably well with previous estimates obtained from growth efficiency experiments and analysis of particle-size spectra. These calculations indicate that potential fish production in Lake Ontario is ~120-fold lower than zooplankton production (for fish averaging 10^8-fold larger in body size as compared to zooplankton).

1983 - Effect of fluctuating lead exposures on lead accumulation by rainbow trout (Salmo gairdneri). See under HODSON, P.V.

1983 - The effect of fluctuating concentrations of waterborne contaminants on their uptake by fish - implications for water quality monitoring. See under HODSON, P.V.

1984 - with CHARLTON, C.C. Copper complexation and toxicity to Daphnia in natural waters. J.Great Lakes Res., 10(4):393-398.

Toxicity of copper to Daphnia magna in artificial medium, artificial medium plus algae, and natural water from Hamilton Harbour and Lake Ontario was determined, with and without added Tris, in order to test the assumption that free cupric ion concentrations are the same in equivalently toxic media even when total copper concentrations vary. Free cupric ion concentrations were calculated from the increase in the total copper concentration tolerated after Tris addition and from cupric ion electrode measurements. Copper toxicity was greatest in inorganic medium, lowest in inorganic medium plus algae and in Hamilton Harbour water, and intermediate in lake water. However, after Tris addition, toxicity was greatest in lake water and lowest in inorganic medium and inorganic medium plus algae. Both the bioassay and electrode data indicate that free cupric ion concentrations differ in different test waters when toxicity is the same. Free metal concentrations do not, therefore, provide a good measure of copper toxicity for Daphnia in natural waters.

BORGMANN, U.(cont.)

1984 - with RALPH, K.M. Copper complexation and toxicity to freshwater zooplankton. Arch.Environm.Contam.Toxicol., 13:403-409.

The effect of copper on the growth rate of cyclopoid copepods and survival of rotifers was determined in natural water with and without addition of the complexing agent Tris. Free copper concentrations were estimated, both by cupric ion electrode and from the bioassay data, making use of the known complexing ability of Tris and the increase in total copper tolerated after Tris addition. Growth rates of copepods were directly related to free copper concentrations indicating that the copper-Tris complex was not toxic to these animals. Rotifer survival was similar at equivalent free copper concentrations in water with and without 1 mmole/L Tris, but additions of 3 mmole/L Tris resulted in slightly lower free copper at equivalently toxic total copper concentrations. Free copper concentrations calculated from bioassay data compared well with electrode measurements in all cases except when calculated using the 3 mmole/L Tris data for rotifers, when free copper concentrations were slightly overestimated.

1984 - with SHEAR. H., & MOORE, J. Zooplankton and potential fish production in Lake Ontario. Can.J.Fish.Aquat.Sci., 41:1303-1309.

We calculated the annual production of epilimnetic crustacean zooplankton in Lake Ontario from data on the abundance of each species and its eggs, and from predictions of egg development times. Bosmina longirostris is the most productive species at the nearshore stations whereas Diacyclops thomasi is the most productive offshore. Total crustacean zooplankton production is fairly uniform throughout the lake, both nearshore and offshore, with the possible exception of somewhat reduced production at the western end of the lake. Average total production was estimated at 15 $g.m^{-2}.yr^{-1}$. Using a recent estimate of particle-size-conversion efficiency in Lake Ontario, obtained from data on contaminant concentrations in aquatic biota, we predicted potential fish production in the lake for various sizes of fish. From published data on the commercial fish harvest from 1910 to 1930, a time period when commercial production was at a maximum, we estimate that the past commercial harvest for pelagic species may have been 20 percent or more of our predicted potential production.

1984 - Lead contamination of the Great Lakes and its potential effects on aquatic biota. See under HODSON, P.V.

1985 - Predicting the effect of toxic substances on pelagic ecosystems. Sci.Total Environm., 44:111-121.

Recent advances in the description of pelagic ecosystems using the biomass size spectrum can be adapted to predict the effect of toxic substances on whole ecosystems. The method is demonstrated using Lake Ontario as an example. First, the shape of the biomass size spectrum is predicted. Using a previously published estimate of particle-size-conversion efficiency (-log(biomass conversion efficiency/log(predator-prey size ratio)), and an estimated exponent

BORGMANN, U.(cont.)

of the allometric relationship between body size and turnover rate of 0.24, the biomass over logarithmically equal size classes in Lake Ontario is estimated to be proportional to body size raised to the exponent -0.02. The biomass within various size classes is then estimated from data on zooplankton and phytoplankton biomass. Total biomass, from algae to fish, is estimated to be 7-16 $g.m^{-2}$ dry weight. The change in biomass and production over various size classes after addition of a toxic substance can then be predicted if the total nutrient load remains relatively constant and if the effect of the substance on biomass conversion efficiency is known. A toxicity sufficient to decrease growth and conversion efficiency by 50 percent is predicted to reduce production of large fish by 91 percent, but phytoplankton production by only 12 percent in the lake. Fish biomass is predicted to drop substantially, phytoplankton biomass should rise, and zooplankton biomass should remain relatively unaffected.

1985 - with RALPH, K.M. Feeding, growth, and particle-size-conversion efficiency in white sucker larvae and young common shiners. Environm.Biol.Fish., 14(4):269-279.

Instantaneous feeding, assimilation, and growth rates for white sucker larvae and young common shiners and guppies (1-2 mg initial dry weight) were measured. Food consisted of natural zooplankton. Linear relationships were obtained between growth and feeding rates for instantaneous feeding rates up to 0.5 $mg^{-1}.day^{-1}$. Maximum gross conversion efficiencies (K_1) were 0.26, 0.31, and 0.24 for suckers, shiners, and guppies respectively. Particle-size-conversion efficiency (-log K_1 per log predator-prey size ratio) was 0.15 for suckers, 0.14 for shiners, and 0.18 for guppies. These values are lower than most available estimates of particle-size-conversion efficiency for carnivorous zooplankton and piscivorous fish, indicating that young planktivorous fish are among the most efficient predators at transferring biomass up the biomass size spectrum in aquatic ecosystems.

1986 - with RALPH K.M. Effects of cadmium, 2,4-dichlorophenol, and pentachlorophenol on feeding, growth, and particle-size-conversion efficiency of white sucker larvae and young common shiners. Arch.Environm.Contam.Toxicol., 15:473-480.

Feeding rates, growth rates, and biomass conversion efficiencies were determined for white sucker larvae and young common shiners fed natural zooplankton during one week exposures to cadmium (suckers and shiners), 2,4-dichlorophenol (DCP)(shiners only), or pentachlorophenol (PCP)(shiners only). All three toxicants significantly ($P < 0.01$) reduced growth rates at sublethal concentrations. Growth rates were reduced up to 67 to 100 percent by DCP and cadmium, but the effect was smaller (a 25 percent reduction) for shiners. Feeding rates were not significantly affected by cadmium or DCP exposure, but shiners exposed to PCP had significantly increased feeding rates. All toxicants, therefore, reduced conversion efficiencies by > 50 percent at sublethal concentrations. Toxicants which reduce conversion efficiency have

BORGMANN, U.(cont.)
the potential for reducing the production of top predators (large piscivores) by an amount greater than the relative effect on any one trophic level (as demonstrated in laboratory experiments) because reductions in efficiency over multiple trophic levels are cumulative.

CAIRNS, V.W.
1979 - Proceedings of the Fifth Annual Aquatic Toxicity Workshop , November 7-9, Hamilton, Ontario. See under WONG, P.T.S.

1983 - RUBY, S.M., & CAIRNS, V. Implications of testicular constrictions on spermatogenesis in Lake Ontario lake trout, Salvelinus namaycush. J.Fish Biol., 23:385-395.

This study examines the histological significance of a testicular anomaly among hatchery-raised lake trout, Salvelinus namaycush, introduced into Lake Ontario as yearlings and subsequently recaptured at ages ranging from 4 to 7 years. The anomaly has been termed a constriction. Histological examination revealed that lake trout with constricted testes demonstrated delayed cycles of spermatogenesis throughout the testes at spawning time compared with normal testes. Constrictions were formed when spermatogonia within an adjacent group of lobules failed to undergo mitosis, hypertrophied and were subsequently resorbed. The walls of these lobules subsequently collapsed and were reabsorbed and replaced by dense fibrous connective tissue. The significance of these observations in relation to hormonal mechanisms and its potential effect upon reproduction in these fish is discussed.

1984 - with HODSON, P.V., & NRIAGU, J.O.(eds.), Contaminant Effects on Fisheries. John Wiley & Sons. ISBN 0-471-88014-0.

CARPENTER, G.F.
1974 - A proposed method suitable for large-scale surveys of biomass in lakes. J.Fish.Res.Bd.Can., 31:327-328.

A method for studying plankton biomass by comparing the results between plankton-net hauls and an integrated water column sample is described. Filtering the planktonnet sample through glass-fiber filter papers would yield planktonnet phytoplankton plus zooplankton biomass. Filtering the integrator sample would yield total phytoplankton biomass. Sieving part of this sample would give direct estimates of net and nannoplankton which could be used in combination with the values of net plankton biomass to give estimates of total biomass and zooplankton biomass.

Ash-free dry weight is recommended instead of dry weight biomass. The results are easy to produce, are comparable with other parameters such as particulate carbon and nitrogen, and are in units which may be used in the determination of trophic status or nutrient budgets for a lake.

1974 - with MANSEY, E.L., & WATSON, N.H.F. Abundance and life history of Mysis relicta in the St.Lawrence Great Lakes. J.Fish.Res.Bd.Can. , 31:319-325.

CARPENTER, G.F.(cont.)

In sampling on Lakes Ontario, Erie, and Superior during three cruises from spring to fall, and on Lake Huron during eight cruises, Mysis relicta was generally not taken or not abundant in waters less than 25 m in depth. Its abundance appeared to increase with depth at least up to 200 m. Populations appeared to be concentrated in waters 125-100 m deep during summer and more dispersed during spring and fall. Highest numbers were found in Lake Superior, followed by Lakes Ontario and Huron. A small localized population was found in the deep eastern part of Lake Erie.

Size-frequency distributions from the various cruises on Lakes Superior, Huron, and Ontario indicated differences in life cycles of the mysid in the three lakes. In Lake Superior there was one major period of recruitment, from February to July, and the generation time appeared to be 2 yr. In Lakes Huron and Ontario recruitment appeared to occur from February to August and to be separated into a winter and a summer period; each of the generations appeared to mature in 18 mo.

1974 - Seasonal abundance of crustacean zooplankton and net plankton biomass of Lakes Huron, Erie, and Ontario. See under WATSON, N.H.F.

1975 - Problems in the monitoring of biomass. See under WATSON, N.H.F.

CARTER, J.C.H.(under contract)

1975 - Seasonal abundance and horizontal distribution of planktonic crustacea of Georgian Bay. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (588).

Samples were taken from Georgian Bay and the North Channel from May to December, 1974, and analyzed with respect to species composition and abundance, and seasonal and horizontal distribution. Eleven species of Cladocera and twelve of Copepoda were found. Cyclops bicuspidatus thomasi comprised more than 50 percent of all planktonic crustacea. Maximum numbers of Cladocera, Cyclopoida and Calanoida were found in midsummer, with Cyclopoida and Calanoida having a second smaller peak in December.

When considering crustacean density in relation to phosphorus loading and surface chlorophyll a, it appears that the level of eutrophication of Georgian Bay is lower than that of Lake Huron and slightly higher than Lake Superior.

No data on heat content is yet available but it appears that warm water accumulated in the east end of Georgian Bay and the North Channel. This accumulation probably contributes to the high numbers of Cladocera found in the eastern region and North Channel in spring and early summer. The planktonic crustacea in the central and western regions is dominated by the Copepoda.

Differences between open and enclosed water are exemplified by greater numbers of Copepoda and lower numbers of Cladocera in Georgian Bay than at Parry Sound.

CHARLTON, C.C.

1984 - Copper complexation and toxicity to Daphnia in natural waters. See under BORGMANN, U.

COLLINS, R.H.

1984 - with KELSO, J.R.M., LIPSIT, J.H., & MOORE, J.E. Phytoplankton production as estimated by the C^{14} technique, and populations contributing to production 1980/81/82, in the Turkey Lakes, Ontario, watershed. Can.Techn.Rept.Fish.Aquat.Sci., (1191).

The Turkey Lakes calibrated watershed consists of a series of four lakes (five basins) underlain by sparingly soluble silicate bedrock. Lowest pH's and alkalinities occured in the headwater lake and increased downstream. Carbon assimilated (measured by *in situ* C^{14} incubation) was greatest between one and four metres in all lakes. Production was low in winter, <0.5 mg $C.m^{-3}h^{-1}$, and increased during summer. Carbon assimilated in the ice-free period was greatest in the shallowest lake and lower in the larger, deeper lakes of the watershed. Production followed the order imposed by lake depth. The headwater lake did not develop the bloom/crash change in phytoplankton abundance or species composition that occured in all the other lakes. Peaks in production coincided with peaks of algal abundance. Cyanophytes were consistently the dominant algal group with the species contributing to peaks in phytoplankton abundance varying from lake to lake.

1984 - An attempt at assessing abundance and distribution of pink salmon (*Oncorhynchus gorbuscha*) prior to their entry of spawning streams. See under KELSO, J.R.M.

COOK, D.G.

1974 - with JOHNSON, M.G. Benthic macroinvertebrates of the St.Lawrence Great Lakes. J.Fish.Res.Bd.Can., 31:763-782.

The history of Great Lakes benthic research from 1870 to the present is briefly reviewed. An examination of the status of taxonomic work on benthic components, and a consideration of the zoogeographical history of the benthos leads to a discussion of bottom communities and macroinvertebrate production in the five major lakes.

Profundal communities throughout the lakes are dominated by the glaciomarine relict amphipod *Pontoporeia affinis* and various species of Oligochaeta, Sphaeriidae, and Chironomidae. The specific composition of these components, and natural and recently imposed changes in their proportions within communities are examined. Population densities and standing stocks, and the proportion of oligochaetes in communities, all tend to increase in response to a natural gradient in productivity inferred from increasing concentrations of parameters such as organic matter and water hardness. Man's influence on water quality anywhere along this gradient compounds the effects of natural factors towards tubificid communities of predictable species composition; *Limnodrilus hoffmeisteri*, *L.claparedeianus*, *L.cervix*, *L.maumeensis*, *Peloscolex multisetosus*, and often *Tubifex tubifex*. The ameliorating influence of water depth is shown in Lake Erie where the change in community composition reflects improving profundal water quality from west to east - a reversed model of the Great Lakes system as a whole.

1975 - A preliminary report on the benthic macroinvertebrates of Lake Superior. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (572).

COOK, D.G.(cont.)

Based on a uniform grid pattern of about 400 stations, our lake-wide estimate of the total macrobenthos in Lake Superior (for May, 1973) is 525/m^2, composed of 34 percent Pontoporeia affinis, 26 percent Oligochaeta (dominated by Stylodrilus heringianus and Mesenchytraeus), 3.2 percent Nematoda, 6 percent Spaeriidae, and 3 percent Chironomidae (dominated by Heterotrissocladius). Biomass estimates emphasize the numerical dominance of P.affinis and oligochaetes but show nematodes to be of less importance; standing stocks (ash-free dry weights) averaged about 0.05 g/m^2 lakewide, to which P.affinis contributed 51 percent, oligochaetes 28 percent, nematodes 11 percent, and sphaeriids and chironomids 4 percent each.

On the basis of total macroinvertebrate abundance, standing stocks, species diversity and taxonomic composition, nine major regions of Lake Superior were recognised; zones were drawn to minimize the very large variation in population sizes and composition, and because of the extensive sampling pattern may be expected to reflect major community types in the lake. The following major trends are clear: 1) benthic populations increased dramatically towards the east end of the lake, culminating in the relatively dense fauna of Whitefish Bay (3000/m^2; 0.48 g/m^2) ; 2) the abundance of most benthic components was negatively correlated with depth; 3) faunal abundance was negatively correlated with the organic carbon content of the sediment; 4) abundance was positively correlated with the sediment's mean particle diameter; i.e. coarse-grained glaciolacustrine sediments were capable of supporting higher populations than the fine-grained muds.

The impoverished fauna of the extreme western basin of the lake indicates that the area may be in some ecological danger from the mining activities on the northwest shore.

1975 - with HILTUNEN, J.K. Phallodrilus hallae, a new tubificid oligochaete from the St.Lawrence Great Lakes. Can.J.Zool., 53:934-941.

The predominantly marine tubificid genus Phallodrilus is defined, a key to its nine species constructed, and an illustrated description of Phallodrilus hallae n.sp. from the St.Lawrence Great Lakes presented. The species is distinguished from other members of the genus by its well-developed atrial musculature, extensions of which ensheath the posterior prostatic ducts.

Phallodrilus hallae n.sp. is a small worm which is widely distributed in the sublittoral and profundal benthos of Lake Superior; lakewide it occured in mean densities of 50 individuals per square metre. Available records indicate a more restricted distribution in Lake Huron and Georgian Bay. We suggest that P.hallae n.sp. is either a glaciomarine relict species, or that it entered the Great Lakes system at the time of the marine transgression of the St.Lawrence valley. The apparent restriction of P.hallae n.sp. to waters of high quality suggests that it may be a sensitive oligotrophic indicator species.

1975 - A preliminary report on the benthic macroinvertebrates of Georgian Bay and North Channel. See under LOVERIDGE. C.C.

COOLEY, J.M.

1977 - Filtering rate performance of *Daphnia retrocurva* in pulp mill effluent. J.Fish.Res.Bd.Can., **34**:863-868.

Laboratory experiments were carried out with radioactive *Scenedesmus* to determine the effect on filtering rate of *Daphnia retrocurva* of exposure to different dilutions of raw pulp mill effluent in lake water. Filtering rate decreased progressively as the exposure time in 5 and 10 percent effluent increased. Most animals seemed able to recover from brief exposures, but with increased time spent in effluent, larger proportions of the animals did not filter when the food was presented.

1977 - Environmental impacts of once-through cooling systems. In; Can.Dept.Fish.Environm., *Electric Power Production and Transmission in Ontario from an Environmental Perspective. Part II*:90-104.

1977 - CONFER, J.L., & **COOLEY, J.M.** Copepod instar survival and predation by zooplankton. J.Fish.Res.Bd.Can., **34**:703-706.

The survivorship of each instar of three cohorts of *Leptodiaptomus minutus* from Bluff Lake, Nova Scotia, is presented. High naupliar mortality but low copepodite mortality occured. The previously reported values for the predation rate and size selection of prey by omnivorous zooplankton are compared with the observed mortality rates for the different sizes of instars. We estimate that predation by the omnivorous zooplankton could account for most of the naupliar mortality. Our analysis supports Dodson's hypothesis that size-selective predation by zooplankton can be a significant factor determining the proportion of a cohort that reaches maturity.

1978 - The effect of temperature on the development of diapausing and subitaneous eggs in several freshwater copepods. Crustaceana, **35**(1):27-34.

Subitaneous egg development was measured at 5 to 7 temperatures using freshly caught zooplankton for two cyclopoids from the Bay of Quinte, on Lake Ontario (*Diacyclops bicuspidatus thomasi* (S.A.Forbes, 1882) and *Mesocyclops edax* (S.A.Forbes, 1881)) and two diaptomids from Bluff Lake, Nova Scotia (*Leptodiaptomus minutus* (Lilljeborg, 1889) and *Agliodiaptomus spatulocrenatus* Pearse, 1906). Development times for first naupliar instars of the two diaptomids were also estimated.

1978 - with **MINNS, C.K.** Prediction of egg development times of freshwater copepods. J.Fish.Res.Bd.Can., **35**:1322-1329.

Available literature data on the relationship between freshwater copepod egg development time and temperature were summarized and fitted where possible to Belehradek's temperature function

$$D = a(T - \alpha)^b$$

where D is development time, T is temperature, a, b, and α are fitted constants. In the calanoids, and to a lesser extent

COOLEY, J.M.(cont.)

cyclopoids, a and α were predictably related as were (α and *in situ* egg hatching temperature (T_H) when b was assumed to be constant for all copepods. This information was used to describe a simple procedure whereby a curve relating egg development and temperature could be constructed by only knowing T_H and applying it to Belehradek's temperature function.

1984 - Analysis of the response to the use of 'adaptive environmental assessment methodology by the Great Lakes Fishery Commission. See under MINNS, C.K.

1986 - with MOORE, J.E., & GEILING, W.T. Population dynamics, biomass, and production of the macrozooplankton in the Bay of Quinte during changes in phosphorus loadings. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), *Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario*. Can.Spec.Publ.Fish.Aquat.Sci., (86):166-176.

The Bay of Quinte on Lake Ontario has become 'culturally eutrophic' in the last 100 yr because of excess input of phosphorus. The macrozooplankton community is dominated by small-bodied cladocerans such as *Eubosmina coregoni*, *Bosmina longirostris*, and *Chydorus sphaericus* in both the shallow hypereutrophic upper part of the bay and in the deeper mesotrophic lower part of the bay. It was anticipated that species composition and production by zooplankton would change in response to scheduled reduction in phosphorus removal which began in 1978. As of the 1983 field season, no such major changes have been recorded. It may be that predation of zooplankton plays a greater role than trophy in determining overall production and species composition at this point of the bay's recovery.

1986 - Trophic structure and interactions in the Bay of Quinte, Lake Ontario, before and after point-source phosphorus control. See under MINNS, C.K.

CULP, L.R.

1975 - Chlorophyll *a* and primary production in Georgian Bay, North Channel and Lake Huron, April to December, 1974. See under WATSON. N.H.F.

1975 - Chlorophyll *a* and primary production in Lake Superior, May to November, 1973. See under WATSON, N.H.F.

1978 - Relative importance of nannoplankton in Lake Superior phytoplankton biomass and community metabolism. See under MUNAWAR, M.

1986 - Temporal and spatial trends in metal loadings to sediments of the Turkey Lakes, Ontario. See under JOHNSON. M.G.

DERMOTT, R.M.

1978 - Benthic diversity and substrate-fauna associations in Lake Superior. J.Great Lakes Res., 4(3-4):505-512.

The benthic community of Lake Superior was dominated by *Pontoporeia*

DERMOTT, R.M.(cont.)

affinis, Stylodrilus heringianus, the Enchytraeidae and Pisidium conventus. Both total abundance and the low benthic diversity displayed an increase from west to east. The biomass diversity H' weight ranged from 0.29 in the Duluth Basin to 1.22 near Whitefish Bay. Associations between the sediment variables and dominant species present indicated that the effects of depth, percent sand and mean particle size were predominant. The Sphaeriidae, Chironomini, Pontoporeia, and Rhyacodrilus were negatively associated with depth, while the Nematoda, Chironomini, and Rhyacodrilus were negatively associated with sand. Stylodrilus and Sphaeriidae were negatively associated with the sediment zinc levels.

1981 - Ingestion rate of the burrowing mayfly Hexagenia limbata as determined with ^{14}C. Hydrobiologia, 83:499-503.

The effects of nymph size and temperature on the ingestion rate of Hexagenia limbata were investigated using ^{14}C labelled algae mixed into sediment. Ingestion rate increased with nymph length and temperature. Daily ingestion rates of large 19 mm nymphs burrowing in silt averaged 58 and 192 percent of the dry body weight at 16° and 21°C, respectively. Ingestion of seston due to filter feeding in artificial burrows was insignificant compared to that ingested by burrowing nymphs.

1982 - Chemical and biological status of headwater lakes in the Sault Ste.Marie District, Ontario. See under KELSO, J.R.M.

1984 - SCOTT, B.F., CAREY, J.H., NAGY, E., & DERMOTT, R. The fate of 3-trifluoromethyl-4-nitrophenol (TFM) in quiescent waters and its impact on benthos. Wat.Pollut.Res.J.Can., 19(1):59-65.

The lampricide, 3-trifluoromethyl-4-nitrophenol (TFM) was added to three lined, sedimented ponds to determine the fate of this chemical and its effect on the benthos of quiescent waters. Two ponds were treated with the commercial formulation and the third was treated with purified DFM. Water column, sediment and benthos samples were taken regularly but not necessarily simultaneously. The initial distribution of TFM in the water column was monitored as was the rate of disappearance of TFM which was calculated to be 0.068 day^{-1}.

Appreciable concentrations of TFM were found in the sediment over the two weeks following treatment, with only trace concentrations detected 117 days after treatment. No known decomposition products of TFM were detected in the water or sediment samples. Only the oligochaete and mollusc populations decreased after treatment, but they had returned to levels in the control pond within a year after addition of the chemical.

1984 - Benthic fauna assemblages in Batchawana Bay, Lake Superior. Can.Techn.Rept.Fish.Aquat.Sci., (1265).

The benthic fauna of oligotrophic Batchawana Bay consists of three assemblages dependent on depth and sediment composition. The deep-water fauna is more similar to that of Georgian Bay than that

DERMOTT, R.M.(cont.)

in Lake Superior. As a result of the enclosed nature of the bay, the warm shallows support a fauna more typical of the historical fauna in the now eutrophic embayments of the lower Great Lakes.

1984 - with SPENCE, H.J. Changes in populations and drift of stream invertebrates following lampricide treatment. Can.J.Fish.Aquat. Sci., 41:1695-1701.

The effects of 3-trifluoromethyl-4-nitrophenol (TFM) treatment on invertebrate abundance, recolonization, and drift rates were examined in three Great Lakes tributaries, having a wide range of water hardness. In the softwater streams only philopotamid caddisflies and lumbriculid worms were significantly reduced after the TFM treatment, whereas their abundance in the untreated stream sections was unchanged. Treatment of the hardwater stream resulted in a dramatic mortality of leeches. Abundance of soft-bodied oligochaetes and Turbellaria were significantly reduced, while numbers of Simuliidae, Hydropsyche, and Baetis increased 14 d after treatment. Daytime drifting rates of the Annelida, Turbellaria, Amphipoda, Glossosomatidae, and Tipulidae increased significantly during the lampricide treatment. Increased drift rates rather than mortality appears to be the major impact of the lampricide on invertebrate communities.

1985 - Lake Ontario long term biological monitoring program: 1981, 1982 data base. See under JOHANNSSON, O.E.

1985 - Lake Ontario long term biological monitoring program: report for 1981 and 1982. See under JOHANNSSON. O.E.

1986 - with LUM, K.R. Metal concentrations in the annual shell layers of the bivalve Elliptio complanata. Environm.Pollut., (Ser. B), 12:131-143.

Levels of four metals were measured in the shells of Elliptio complanata, collected from three localities in the Great Lakes, having widely different levels of contamination. The levels of ten metals were measured in the outermost shell and overlying periostracum, cut from each of the annual rings of two shells. Zn(unlike Pb) displayed a much greater affinity to the soft tissues than the shell. Levels of Al, Cu, Fe, Ni, Pb, and Zn were significantly higher in the outer periostracum of the shell than in the inorganic prismatic shell layer. In spite of high Pb levels in industrial effluent at one of the locations, inorganic Pb was not deposited in the prismatic shell layer. Metal concentrations in the periostracum did not follow the chronological trends in the prismatic layer. Levels of Al, Fe, and Mn decreased with clam age, whereas concentrations of Cu and Zn were greatest during years of fastest growth.

1986 - with TIMMINS, C.A. Occurence and spawning of pink salmon, Oncorhynchus gorbuscha, in Lake Ontario tributaries. Can.Field-Nat., 100(1) :131-133.

DERMOTT, R.M. (cont.)

Pink salmon were confirmed present in seven tributaries of Lake Ontario during the 1983 spawning period. Spawning occured in three of the streams. Lake Ontario fish were smaller than fish from lakes Erie and Huron.

1986 - with KELSO, J.R.M., & DOUGLAS, A. The benthic fauna Of 41 acid sensitive headwater lakes in north central Ontario. Wat.Air Soil Pollut., 28:283-292.

The benthic fauna of 41 nonhumic, softwater lakes situated north of Lakes Superior and Huron were sampled during 1980. The pH range of the lakes sampled was 4.6 to 7.7. The benthic infauna displayed regional differences in abundance and composition, with large variation within each district. Total abundance, biomass, and number of taxa were not correlated with lake pH or alkalinity. The Chironomidae displayed a slight change in percent composition of the major species ($p < 0.2$) with lower pH. The Tanytarsini and *Chironomus salinarius* group decreased, while *C.anthracinus* group increased in relative abundance in those lakes with lower pH. Other factors appear to control the distribution of the various invertebrate orders, with depth and sediment nature being important variables.

DIXON, D.G. (Post-Doctorate Fellowship)

1981 - with HILTON, J.W. Influence of available dietary carbohydrate content on tolerance of waterborne copper by rainbow trout, *Salmo gairdneri* Richardson. J.Fish Biol., 19:509-517.

The effect of increased available dietary carbohydrate on the tolerance of waterborne copper by rainbow trout was investigated. Trout were reared for six to eight weeks on one of four isocaloric and isonitrogenous diets which varied in available carbohydrate content due to either processing (extrusion v. steam-pelleting) or supplementation with cerelose (0 or 21 percent). The incipient lethal level (ILL) of copper for trout reared on the low-available-carbohydrate steam-pelleted diet was 350 $\mu g.l^{-1}$, significantly higher than the 276 $\mu g.l^{-1}$ shown for trout reared on the high-available-carbohydrate extruded diet. The ILL of copper for the low-carbohydrate group (0 percent cerelose) was 408 $\mu g.l^{-1}$, significantly higher than the ILL of 246 $\mu g.l^{-1}$ of trout reared on the high-carbohydrate diet (21 percent cerelose). Increased available dietary carbohydrate resulted in increased liver glycogen content and liver-body weight ratios and decreased liver protein content. Significant correlations were evident between waterborne copper tolerance and liver glycogen, liver-body weight ratios and liver protein. Relative to those on high carbohydrate diets, livers of fish on low-carbohydrate diets contained higher concentrations of copper after seven days of exposure to 0 or 196 $\mu g.l^{-1}$ of copper. The elevated liver glycogen levels, resulting from increased dietary carbohydrate, are thought to have impaired liver function, thus reducing copper tolerance.

1983 - The use of LD50 determination by intraperitoneal injection as a rapid method for initial estimates of pollutant toxicity to fish. See under HODSON, P.V.

DIXON, D.G.(cont.)

1984 - The use of rapid biological indicators of toxicant stress to generate biological data bases for QSAR. See under HODSON, P.V.

1985 - Plasma leucine aminonaphthylamidase as an indicator of acute sublethal toxicant stress in rainbow trout. See under HODSON, P.V.

1985 - The role of biochemical indicators in the assessment of ecosystem health - their development and validation. See under HODSON, P.V.

DUNN, J.L.

1984 - Determination of dialkyllead, trialkyllead, tetraalkyllead and lead (II) compounds in sediment and biological samples. See under WONG, P.T.S.

1985 - Occurence of alkyllead compounds in the Detroit and St.Clair Rivers. See under WONG, P.T.S.

FITZSIMONS, J.D.

1981 - Occurence of *Mysis relicta* Lovén in the western basin of Lake Erie (Mysidacea). Crustaceana, 41(2):217-219.

Heretofore *M.relicta* has been known only from the central and eastern basins of Lake Erie. Its presence in the central basin at present seems unlikely, and it is uncommon in the eastern basin. It is, however, very abundant in the other Great Lakes where it is considered an important member of the deep water community. On June 12, 1979, during a water quality cruise in the western basin of Lake Erie, four live *Mysis relicta* Lovén, 1861, were collected in a single epibenthic sled haul.

1983 - The influence of the Niagara River on contaminant burdens of Lake Ontario biota. See under WHITTLE, D.M.

1986 - Biological tissue archive studies. See under HYATT, W.H.

GLOOSCHENKO, W.A.

1971 - The effect of DDT and dieldrin upon ^{14}C uptake by *in situ* phytoplankton in Lakes Erie and Ontario. Proc.14th.Conf.Great Lakes Res.1971:219-223.

In situ studies were performed upon the effects of DDT and dieldrin to phytoplankton in Lake Ontario in May, 1970 and Lake Erie in July and October, 1970. To water samples, concentrations of 1, 10, 100, and 1000 ppb DDT and dieldrin (Lake Erie only) were added. The response of the phytoplankton was measured by ^{14}C uptake over 5-hr intervals.

On Lake Ontario, 1 ppb DDT was sufficient to cause a decrease of C^{14} uptake by 12.3 percent. On four stations occupied in Lake Erie in July, and three occupied in October, DDT at 1 ppb caused decreases in ^{14}C uptake from 4.2 - 28.1 percent in July and 1.2 - 29.1 percent in October. Dieldrin decreased ^{14}C uptake to a greater extent. A decrease of 30.7 - 74.7 percent was found at at 1 ppb in July, and 9.0 - 36.4 percent in October. At the higher

GLOOSCHENKO, W.A. (cont.)

concentrations used of 10, 100, and 1000 ppb, greater reduction of ^{14}C was noticed.

The inhibition of ^{14}C uptake by DDT and dieldrin does not appear to be important to the Great Lakes in situ except possibly in local areas of high run-off from agricultural sources. The major problem appears to be concentration of these pesticides by algae and transfer to higher trophic levels.

1972 - MENON, A.S., GLOOSCHENKO, W.A., & BURNS, N.M. Bacteria-phytoplankton relationships in Lake Erie. Proc.15th.Conf.Great Lakes Res.1972:94-101.

Bacterial densities in Lake Erie exhibited two maxima, in August and late October and two minima, in late September and early December. Highest bacterial densities were found in the eutrophic western basin and the least in the mesotrophic eastern basin. Vertical distribution of bacteria was fairly uniform when the water was unstratified. During summer stratification, hypolimnion bacterial densities increased steadily and reached maximum levels in late August, coinciding with the period of maximum phytoplankton development. A significant positive correlation was found between bacteria, chlorophyll a and particulate organic carbon in the hypolimnion during this period.

Complex bacteria-phytoplankton relationships existed in Lake Erie, of which four types are described in this study. Generally, bacteria appeared to be dependent on the nutrients derived from the excretion and degradation of phytoplankton.

1972 - with MOORE, J.E., & VOLLENWEIDER, R.A. The seasonal cycle of phaeo-pigments in Lake Ontario with particular emphasis on the role of zooplankton grazing. Limnol.Oceanogr., 17(4):597-605.

The annual cycles of chlorophyll a, pheo-pigments, and zooplankton in Lake Ontario were studied on 32 stations during 13 cruises in 1970. Highest amounts of chlorophyll a were found in inshore waters. The seasonal cycle of phytoplankton biomass as measured by chlorophyll a showed three patterns: 1) a unimodal distribution in the deeper waters which are last to warm up in late spring; 2) a bimodal pattern, with spring and fall peaks, mainly along the central basin and north and south shores; 3) a series of three pulses in nutrient-rich areas and in the warmer eastern region of the lake. Zooplankton biomass increased eastward in the direction of increasing heat content.

Pheo-pigments were low during the spring increase of phytoplankton, but their amount relative to that of chlorophyll a was significantly correlated ($r = +0.896$) with zooplankton abundance. Highest pheo-pigments were found in the eastern basin of the lake.

The need to correct chlorophyll a values for pheo-pigments is emphasized especially when zooplankton grazers are abundant.

1973 - with MOORE, J.E. Surface distribution of chlorophyll a and primary production in Lake Huron, 1971. Fish.Res.Bd.Can., Techn.Rept., (406).

GLOOSCHENKO, W.A.(cont.)

During the period April-December, 1971, chlorophyll a and primary production measurements were made on 8 cruises on Lake Huron. The highest chlorophyll a and production values were measured in Saginaw Bay, with respective ranges of 7.8 - 37.5 mg/m^3 and 4.1 - 158.4 mgC/m^3/hr. In the main portion of the lake, chlorophyll a ranged from 0.0 - 12 mg/m^3 while primary production values up to 21.6 mgC/m^3/hr were measured. Higher values of both chlorophyll a and primary production generally occured in inshore waters along the southern half of the lake, both on the Michigan and Ontario shores, while the northern half of the lake is low in these two parameters.

Other than highly eutrophic Saginaw Bay, the rest of the lake appears to be classified as oligotrophic.

1973 - with MOORE, J.E. The effect of citrate on phytoplankton in Lake Ontario. In; G.E.GLASS(ed.), Bioassay Techniques and Environmental Chemistry:321-324. Ann Arbor Sci.Publ.Inc. ISBN 0-250-40017-0.

All previously mentioned studies on the effect of citrate on algae utilized unialgal cultures, a condition atypical of that found in natural aquatic ecosystems. In order to investigate the effects of citrate upon phytoplanktonic algae, field bioassay studies were performed in Lake Ontario and Hamilton Harbour, an embayment of the lake subjected to high discharges of industrial effluents primarily from steel mills.

1973 - with MOORE, J.E., & VOLLENWEIDER, R.A. Chlorophyll a distribution in Lake Huron and its relationship to primary productivity. Proc.16th.Conf.Great Lakes Res.1973:40-49.

Water samples (0-10 m integrated) were collected from 46 stations on Lake Huron, including Saginaw Bay, on eight cruises between April and December, 1971, for chlorophyll a and primary production measurements. With the exception of Saginaw Bay and U.S. inshore waters to the south of the Bay mouth, chlorophyll a values were quite low with maxima rarely exceeding 3 µg/l. The seasonal cycle of chlorophyll a in most of the lake was weakly bimodal with maxima in mid-late spring and mid-autumn. The summer minimum was not pronounced. Sharp gradients of chlorophyll a occured into Saginaw Bay, where the highest chlorophyll a values yet observed in the Great Lakes were noted. Between April and December, the mean chlorophyll a value for the lake (excluding Saginaw Bay) was between 1 and 2 µg/l, indicating extreme oligotrophy.

Primary production measurements showed the same pattern as chlorophyll a, with highest values in Saginaw Bay. Integral photosynthesis values, mg/m^2 hr or year, were roughly half that of Lake Ontario. Assimilation numbers, mgC/mg chlorophyll a hr, were highly positively correlated with temperature. Highest numbers were in Saginaw Bay, indicating the enriched nutrient status in the Bay.

1974 - Seasonal variations of temperature and nutrients in the surface waters of Lakes Ontario and Erie. See under VOLLENWEIDER, R.A.

1974 - with MOORE, J.E., & VOLLENWEIDER, R.A. Spatial and temporal distribution of chlorophyll a and pheopigments in surface waters of

GLOOSCHENKO, W.A.(cont.)
Lake Erie. J.Fish.Res.Bd.Can., 31:265-274.

Chlorohyll a analyses including pheopigments were made on water samples taken on 10 cruises on Lake Erie between April and December, 1970. The highest mean chlorophyll a values of approximately 11 µg/liter occured in the mid-western basin, with a second maximum of 6 µg/liter off Erie, Pennsylvania. The southern shore is also characterized by high values of chlorophyll to the east of Cleveland, Ohio. The lowest yearly means were found in the eastern portion of the central basin and most of the eastern basin (approximately 3 µg/liter). Ratios of chlorophyll a between the eastern, central, and western basins have a yearly mean of 1:1.4:2.8, respectively; with maximum differences in the summer, i.e. late August, the ratio was 1:1.5:7.2.

Pheopigment concentration in the surface waters reached a maximum in late October corresponding to the fall overturn of the lake and subsequent resuspension of organic matter containing degradation products from the bottom of the lake. No significant correlation was found between zooplankton abundance and pheopigment concentration as in other water bodies studied. This may indicate that zooplankton food chains are primarily detrital in Lake Erie, with grazing of living phytoplankton playing a lesser role compared with more oligotrophic water bodies.

1974 - with MOORE, J.E., MUNAWAR, M., & VOLLENWEIDER, R.A. Primary production in Lakes Ontario and Erie: a comparative study. J.Fish.Res.Bd.Can., 31:253-263.

Primary production values in Lake Ontario were low in winter, reached a maximum in mid-spring, declined during summer, and slightly increased in fall. Rate of increase of production for inshore waters (<20 m depth) was greater, especially in spring and early summer with a greater maximum reached earlier than in offshore waters. Assimilation numbers, mgC fixed/mg chlorophyll a per hour, in Lake Ontario were fairly constant over the lake with a yearly range of 1.2 - 1.6. Primary production showed a linear relationship to chlorophyll a concentration, as also occured in Lake Erie.

Lake Erie primary production varied in its three basins. Seasonally, in the eastern basin, production was highest in spring with a midsummer decline, and small peaks in fall. The western basin had a maximum in midsummer whereas the central basin had peaks in late summer and early fall. Assimilation numbers were highest in the western basin (up to 3.5 mgC/mg chlorophyll a per hour) and lowest in the mid-central basin and eastern basin with values of approximately 1.4 mgC/mg chlorophyll a per hour. A definite westerly increase of assimilation number was observed.

Up to early summer, the two lakes were fairly equal in surface production but integral photosynthesis, mgC/m^2 per hour was higher in Lake Ontario than in Lake Erie. The same was valid in November and December. In summer, Lake Erie was higher in production on both a mgC/m^3 per hour and mgC/m^2 per hour basis. For the period April-December, Lake Ontario's total estimated yield was 170 gC/m^2 whereas for Lake Erie values of 160, 210, and 310 gC/m^2 were found for the eastern, central, and western basins respectively.

GLOOSCHENKO, W.A. (cont.)

1975 - GLOOSCHENKO, V., & GLOOSCHENKO, W.A. Effect of polychlorinated biphenyl compounds on growth of Great Lakes phytoplankton. Can.J.Bot., 53:653-659.

Polychlorinated biphenyls (PCBs) have been used for a variety of industrial applications since 1929 and their presence is now widespread in aquatic and terrestrial ecosystems. In this study, three species of Great Lakes phytoplankton and one common soil alga exhibited growth inhibition when exposed to concentrations of PCB as low as 1 µg/litre while 50 µg/litre was toxic to all cultures. Photosynthesis, measured by $Na_2^{14}CO_3$ uptake was also depressed by PCB additions, but ^{14}C uptake per cell was stimulated at times. Of the four PCB compounds tested, Aroclor 1016 appeared least toxic and Aroclor 1242 was the most toxic, while Aroclors 1221 and 1248 gave intermediate responses.

Examination of cells by electron microscopy showed distortion of chloroplast lamellae and increased cytoplasmic vacuole formation in algal cultures treated with 50 µg/litre PCB. Gross cell morphology changes were also observed under the light microscope.

Water quality criteria recommend that persistent organic chemicals which are toxic in concentrations of 5 µg/litre or less should not exceed environmental levels of more than 1/100th of this amount. Levels of PCBs in water from several areas of Lakes Erie and Ontario currently exceed these concentrations.

GOLINI, V.I. (Post-doctorate Fellow)

1979 - Benthic macro- and meioinvertebrates of Lake Ontario 1977: distribution and relative abundance. Can.Dept.Fish.Environm., Fish.Mar.Serv., MS Rept., (1519).

A total of 29,227 benthic invertebrates sampled from the surficial sediments of Lake Ontario in September 1977 consisted of 41.6 percent Nematoda, 37.5 percent Pontoporeia, 12.4 percent Oligochaeta, 6.5 percent Sphaeriidae, 1.4 percent Chironomidae and 0.6 percent other invertebrates. The nematodes are reported for the first time as the major component of the benthic meiofauna, predominating in mesotrophic biotopes. Abundance of the major taxa sampled lakewide varied inversely with depth. The shallow zone, mean depth 25 m, sustained an average density of 8,849 specimens/m^2, comprising 54.7 percent Nematoda, 20.7 percent Pontoporeia, 12.6 percent Sphaeriidae, 8.5 percent Oligochaeta, 2.1 percent Chironomidae. The intermediate zone, mean depth 70 m, sustained 4,800 specimens/m^2, comprising 51.2 percent Nematoda, 30.3 percent Pontoporeia, 8.6 percent Oligochaeta, 8.0 percent Sphaeriidae, 1.5 percent Chironomidae. The profundal zone, mean depth 151 m, sustained 1,600 specimens/m^2, comprising 58.2 percent Nematoda, 18.4 percent Pontoporeia, 18.5 percent Oligochaeta, 3.5 percent Sphaeriidae, 1.4 percent Chironomidae. An additional 14,129 benthic invertebrates from Toronto Harbour, with mean depth 9 m and density 12,795/m^2 consisted of 92.7 percent Oligochaeta, 5.4 percent Sphaeriidae, 1.1 percent Chironomidae and 0.8 percent other invertebrates. The lakewide abundance of these invertebrates relative to the past 13 years suggests that Lake Ontario is tending toward a more oligotrophic state.

GOLINI, V.I.(cont.)

The chironomidae included 13 genera and 4 species groups found primarily in the shallow zone which contained 48.8 percent of the sampled population. In the shallow zone Micropsectra sp. and Heterotrissocladius changi Saether were ubiquitous, while Chironomus cf.cucini Webb, C.plumosus gr. and Procladius sp. occured in certain other biotopes, hence characterizing this zone generally as meso-oligotrophic with eutrophic point sources. The intermediate zone contained 43.8 percent of the chironomids, including 72 percent Micropsectra sp., 17.2 percent H.oliveri Saether, 5.4 percent H.changi, 3.2 percent Paracladopelma sp. The profundal zone contained 93.8 percent H.oliveri and 6.2 percent Paracladopelma sp. Hence, both these last two zones are characterized strictly as oligotrophic. The chironomid fauna of Toronto Harbour consisted of 64.7 percent C.plumosus L., 33.3 percent Procladius sp. and 2.0 percent Psectrotanypus sp. which characterize this harbour as strictly eutrophic.

HODSON, P.V.

1976 - δ-amino levulinic acid dehydratase activity of fish blood as an indicator of a harmful exposure to lead. J.Fish.Res.Bd.Can., 33:268-271.

The activity of red cell δ-amino levulinic acid dehydratase of rainbow trout (Salmo gairdneri) was depressed after exposure of the fish to lead. Concentrations of lead in water as low as 13 µg/liter caused a significant inhibition of activity after only 4-wk exposure. Assays of this enzyme's activity may provide a short-term indication of long-term harmful effects of lead.

1976 - Computer model for toxicant spills in Lake Ontario. See under MINNS, C.K.

1976 - ANDREW, R.W., HODSON, P.V., & KONASEWICH, D.E.(eds.). Toxicity to Biota of Metal Forms in Natural Water. Internat.Joint Comm., Windsor, Ont.

This publication represents the proceedings of a workshop which discussed the toxicity to biota of metal forms in natural water. The workshop was sponsored by the Standing Committee on the Scientific Basis for Water Quality Criteria of the International Joint Commission's Research Advisory Board and was held in Duluth, Minnesota, on October 7-8, 1975.

The workshop consisted of formal papers on the latest research findings in the area of heavy metal forms (speciation), toxicity and cause-effect relationships. These presentations were followed by two discussion periods: one to evaluate the current 'state of the art' of metal speciation determinations; and the other, to identify the immediate research needs which will enable the establishment of heavy metal objectives for the waters of the Great Lakes on the basis of metal forms rather than total metal concentrations.

1976 - Review of 'Heavy Metals in the Aquatic Environment. An International Conference' by P.A.KRENKAL(ed.). J.Fish.Res.Bd.Can., 33:1865-1866.

HODSON, P.V. (cont.)

1977 - with BLUNT, B.R., SPRY, D.J., & AUSTEN, K. Evaluation of erythrocyte δ-amino levulinic acid dehydratase activity as a short-term indicator in fish of a harmful exposure to lead. J.Fish.Res.Bd.Can., 34:501-508.

The activity of erythrocyte δ-amino levulinic acid dehydratase (ALA-D) of fish is easily measured under a variety of experimental conditions. Exposure of rainbow trout (Salmo gairdneri), brook trout (Salvelinus fontinalis), goldfish (Carassius auratus), and pumpkinseeds (Lepomis gibbosus) to lead consistently inhibited ALA-D within two weeks at concentrations as low as 10, 90, 470, and 90 μg/l, respectively. In rainbow and brook trout these concentrations were closely related to the published minimum effective concentrations causing sublethal harm. There was a significant linear relationship between ALA-D activity and log of blood lead concentration, between ALA-D activity and log of lead in water, and between blood lead and lead in water. Near lethal exposures to cadmium, copper, zinc, and mercury did not significantly inhibit ALA-D activity. Recovery of ALA-D activity of rainbow trout after transfer from 120 μg/l lead to clean water occured in 8 wk. This enzyme provides fast, consistent, specific, and sensitive estimates of lead concentrations causing sublethal harm to fish and may help to relate sources of lead to degree of exposure of fish populations in the field.

1977 - with ROSS, C.W., NIIMI, A.J., & SPRY, D.J. Statistical considerations in planning aquatic bioassays. Proc.3rd.Aquat. Tox.Worksh., Halifax, N.S., Nov.2-3, 1976. Environm.Protect.Serv., Techn.Rept., EPS-5-AR-77-1:15-31.

Detailed understanding of the assumptions and statistical calculations of probit analysis are limited to a few statisticians. For the practitioner, probit analysis using computer programs is a 'black box' method, i.e., the derivation of the results may not be subject to question. This paper examines the results of contrived and real toxicity data using a probit analysis program to illustrate how experimental design (e.g., number of concentrations, fish per tank, and replicates) affects fiducial limits, chi-square, slope and variance of slope. Recommendations are also made for experimental approaches that would provide a more rational bioassay data base to support legal and environmental requirements.

1978 - with MILLARD, E.S. Experimental ecosystems as a means of evaluating the fate and effect of contaminants in aquatic ecosystems. In; J.C.DAVIS, G.L.GREER & I.K.BIRTWELL(eds.), Proceedings of the Fourth Annual Aquatic Toxicity Workshop, November 8-10, 1977, Vancouver, B.C., Can.Dept.Fish.Environm., Fish.Mar. Serv., Techn.Rept., (818):65-87.

Studies of contaminants using a single species do not illustrate the potential for biomagnification, persistence or toxicity in a complex ecosystem. Studies of existing contaminated ecosystems are expensive, time consuming and difficult to accomplish due to the high degree of complexity and size of natural ecosystems. To bridge

HODSON, P.V. (cont.)

this gap, increasing use is being made of small, experimental ecosystems to evaluate contaminant fate and impact. These range from small aquaria in the lab to large enclosures of water in the field. These approaches are reviewed and the utility of results discussed, with some illustrations of experiences at the Great Lakes Biolimnology Laboratory. When the limitations of these methods and their proper role in decision-making is recognized, they provide a fast, valuable means for preliminary assessment of environmental hazard.

1978 - Lead and the aquatic biota. See under WONG, P.T.S.

1978 - with BLUNT, B.R., & SPRY D.J. Chronic toxicity of water-borne and dietary lead to rainbow trout (Salmo gairdneri) in Lake Ontario water. Wat.Res., 12:869-878.

Rainbow trout (Salmo gairdneri) exposed to lead in Lake Ontario water demonstrated a 21-day LC_{50} of 2.4 $mg.l^{-1}$ lead. At lead concentrations ranging from 3 to 120 $\mu g.l^{-1}$, $\log_{10}$ of lead concentrations in most tissues of exposed fish appeared linearly related to $\log_{10}$ of lead concentrations in water. Highest concentrations occured in opercular bone followed by gill and kidney. Lead accumulation by brain was not clearly demonstrated. Exposure to lead in water at concentrations as low as 13 $\mu g.l^{-1}$ caused significant increases in red blood cell (RBC) numbers, decreases in RBC volumes, decreases in RBC cellular iron content and decreases in RBC δ-amino levulinic acid dehydratase activity. No changes were observed in hematocrit or whole blood iron content. The changes indicated increased erythropoiesis to compensate for inhibition of hemoglobin production and increased mortality of mature red blood cells. After 32 weeks exposure to 120 $\mu g.l^{-1}$ lead in water, 30 percent of remaining fish exhibited black tails, an early indication of spinal deformaties. Lead added to food was not available for lead uptake by fish. Lead content of fish exposed to dietary lead was not elevated above control levels and the majority of lead consumed could be accounted for in the faeces. Dietary lead may have slightly inhibited uptake of dietary iron.

1978 - with BLUNT. B.R., & SPRY, D.J. pH-induced changes in blood lead of lead-exposed rainbow trout (Salmo gairdneri). J.Fish.Res.Bd.Can., 35:437-445.

Blood of juvenile rainbow trout (Salmo gairdneri) exposed to lead in water showed increasing lead concentrations as pH of the test water decreased from 10.0 to 6.0. A decrease in pH by 1.0 unit from any reference pH resulted in an increase of blood lead by a factor of 2.1. Since sublethal lead toxicity is related to uptake, these results suggest that toxicity increases as pH decreases. Control experiments indicated that reactions of lead with organic constituents of the test water were complete within 3 h and that blood lead was at equilibrium with water lead within 48 h. Therefore, at the time of blood sampling in the pH experiment, both lead complexation processes in the exposure system, plus lead uptake and release from the blood, were at equilibrium.

HODSON, P.V.(cont.)

1979 - Proceedings of the Fifth Annual Aquatic Toxicity Workshop, November 7-9, 1978, Hamilton, Ontario. See under WONG, P.T.S.

1979 - Metering device for toxicants used in bioassays with aquatic organisms. Progr.Fish-Cult., 41(3):129-131.

The meter described was developed from a design by the author to operate a proportional diluter. The meter is fail-safe and has no moving parts. The pressure developed within an intermittent siphon bottle is used to force toxicant from a reservoir or dispensing bottle. The system has been used for more than 4 years in bioassays lasting up to a year. Coefficients of variation of measured toxicant concentrations less than 10 percent can be easily achieved and the system has not been affected by the temperature fluctuations typical of a laboratory.

1979 - Factors affecting the sublethal toxicity of lead to fish. Proc.Internat.Conf.Managem.Control Heavy Metals Environm., London, 1979:135-138.

Waterborne lead as low as 8 μg/L causes hematological and neurological damage to fish after prolonged exposures. New and published data are reviewed to show how environmental and biological factors affect sublethal lead toxicity. Source of lead, lead concentration, exposure time, water hardness, pH, and organic particulates affect toxicity through changes in availability of lead to fish. Organic forms of lead, fish species, fish age when first exposed, and possibly water hardness and pH, affect toxicity through changes in the permeability of fish to lead. No factor was identified that changed fish sensitivity to lead taken up.

1979 - with BORGMANN, U., & SHEAR, H. Toxicity of copper to aquatic biota. In; J.O.NRIAGU (ed.), Copper in the Environment. Part II; Health Effects: 307-372. John Wiley & Sons.

Lethal effects may be observed over a wide range of copper concentrations (23 to 10,200 μg/l); the variations were primarily a result of the effects of water hardness, organic complexing capacity, and species sensitivity. Numerous histological, physiological, and enzymatic responses of fish to near-lethal copper exposures suggest that osmoregulatory failure during exposure to the metal is the probable cause of death.

Sublethal effects of copper on fish occur at concentrations up to the lethal level. The thresholds of effect, however, are observed at concentrations less than 160 μg Cu/l. The behaviour and growth of salmonids representive the most sensitive parameters measured. Significant effects on avoidance, activity, coughing, appetite, growth, and migration occured at copper concentrations between 4 and 10 μg/l. Physiological responses, including inhibition of gill ATPasc and plasma GOT activities, plus short-term corticosteroid elevation, were also observed between 5 and 10 μg/l. Threshold effects on reproduction, growth, and mortality, and hence fish production, were observed between 10 and 20 μg/l for salmonids, catfish, and walleyes, between 18 and 40 μg/l for fathead minnows, and between 40 and 160 µg/l for bluegills. Finally, disease was induced in eels, salmonids, suckers, and cyprinids at 30 to 60 µg Cu/l. These data indicate that fish populations are adversely affected at copper concentrations well below the lethal level, so that some species could disappear without direct observable mortality.

1979 - with BLUNT, B.R., JENSEN, D., & MORGAN, S. Effect of fish age on predicted and observed chronic toxicity of lead to rainbow trout in Lake Ontario water. J.Great Lakes Res., 5(1) :84-89.

Exposure of rainbow trout (Salmo gairdneri) starting at the egg stage to water-borne lead in Lake Ontario water (hardness of 135 mg $CaCO_3$/L) resulted in black tails (early symptoms of spinal deformaties) at lead concentrations as low as 22 µ g/L. No black tails were observed at 11 µg/L. Previous publications demonstrated that the lowest lead concentration causing black tails in trout exposed from the fingerling stage in Lake Ontario water was 120 µg/L, suggesting that fish exposed from the egg stage are 5 times as sensitive as those exposed from the fingerling stage. Compared to previously published data on fish exposed from the egg stage, blood lead of fish exposed from the egg stage was greater for a similar lead exposure. However, the relationship between blood lead and enzyme inhibition (erythrocyte δ-amino levulinic acid dehydratase) was unchanged. Therefore the increased sensitivity of trout exposed from the egg stage was probably due to enhanced lead accumulation rather than to an enhanced response to the lead taken up. The incidence of black tails at this hardness corresponded well to a prediction based on published lead toxicity at extremes of water hardness.

1980 - HILTON, J.W., HODSON, P.V., & SLINGER, S.J. The requirement and toxicity of selenium in rainbow trout (Salmo gairdneri). J.Nutrit., 110(12):2527-2535.

This study measured the dietary selenium requirement of rainbow trout and their response to excessive levels of dietary selenium. A dietary selenium level of 0.07 µg/g dry feed with a waterborne selenium level of 0.4 ± 0.2 µg/litre and a dietary vitamin E level of 0.4 IU/g dry diet was sufficient to prevent frank selenium deficiency symptoms. Maximal plasma GSH.px activity was obtained at a dietary selenium level between 0.15 and 0.38 µg/g dry feed which is less than the average selenium concentration of commercial diets. Chronic dietary selenium toxicity occured at 13 µg selenium/g dry feed. Major effects of selenium toxicity were reduced growth rate, poor feed efficiency and a high number of mortalities. No histopathological lesions or significant deviation in the investigated blood parameters or liver somatic index were detected in trout raised on diets containing 13 µg selenium/g dry feed. Tissue selenium analysis indicated that trout can maintain homeostasis with dietary selenium levels up to 1.25 µ g/g dry feed. The selenium uptake and accumulation in tissues of trout reared on diets containing in excess of 3 µg/g dry feed may ultimately be toxic to trout if maintained over long periods of time.

HODSON, P.V.(cont.)

1980 - with BLUNT, B.R., & WHITTLE, D.M. Biochemical monitoring of fish blood as an indicator of biologically available lead. Thalassia Jugoslavica, 1(2-4):389-396.

Erythrocyte δ-amino levulinic acid dehydratase (ALA-D), an enzyme involved in hemoglobin synthesis and found in the blood of fish, provides a convenient measure of levels of 'biologically available' lead in the environment. Inhibition of the activity of ALA-D is directly correlated to waterborne lead concentrations and lead uptake by fish. The inhibition is specific for lead, sensitive to low lead concentrations in water or blood, and easily and economically measured in a wide variety of fish species. Preliminary application of this assay to monitoring lead exposure of lake trout (Salvelinus namaycush) from the Lake Ontario indicated its practicality and sensitivity.

1980 - with SPRY, D.J., & BLUNT, B.R. Effects on rainbow trout (Salmo gairdneri) of a chronic exposure to waterborne selenium. Can.J.Fish.Aquat.Sci., 37:233-240.

The 96-h and 9-d LC50s of selenium for rainbow trout (Salmo gairdneri) averaged 8.1 and 6.5 mg.L^{-1}, respectively. A sublethal exposure of rainbow trout from the newly fertilized egg stage until 44 wk posthatch to 4.4 - 53 μg.L^{-1} of waterborne selenium resulted in a variety of subtle responses. Significantly increased mortality of eyed eggs was observed at selenium concentrations greater than or equal to 28 μg.L^{-1} and decreased red blood cell volumes and cellular blood iron at concentrations greater than or equal to 53 and 16 μg.L^{-1}, respectively. Although the highest eyed egg mortality at 47 μg.L^{-1} selenium was double that of control, total mortality was only 6.50 percent. Similarly, the blood parameters decreased from control levels by a maximum of 30 percent and the fish appeared to be compensating for these changes by increased erythropoiesis. Overall, the fish responded to selenium exposure at concentrations between 100 and 250 times the normal background concentrations in surface waters but the level of response was low. Analyses of tissue selenium at 44wk posthatch indicated that residues clearly reflected exposure, that liver, digestive tract, and kidney accumulated the highest residues, that selenium tissue concentrations may be regulated, and that specific tissues provide a better basis for monitoring selenium exposure than whole body analyses.

1980 - with HILTON, J.W., BLUNT, B.R., & SLINGER, S.J. Effects of dietary ascorbic acid on chronic lead toxicity to young rainbow trout (Salmo gairdneri). Can.J.Fish.Aquat.Sci., 37:170-176.

Newly hatched rainbow trout (Salmo gairdneri) exposed to waterborne lead and receiving diets deficient in, or supplemented with, ascorbic acid, developed classical symptoms of lead toxicity and ascorbic acid deficiency. Those exposed to lead showed elevated blood lead concentrations, inhibition of erythrocyte δ-amino levulinic acid dehydratase, darkening of the tail regions and spinal curvatures. Those receiving ascorbate deficient diets showed depletion of carcass, liver, kidney, and brain ascorbic acid concentrations plus spinal curvatures. Fish subjected to both

HODSON, P.V.(cont.)

treatments simultaneously showed no evidence of an enhancement of ascorbate deficiency symptoms by exposure to lead or enhancement or reduction of lead toxicity symptoms by ascorbate deficient or supplemented diets, respectively. These results demonstrate that, although aspects of lead toxicity in fish resemble ascorbic acid deficiency, there is no metabolic interaction between the two factors.

1981 - SPRY, D.J., WOOD, C.M., & HODSON, P.V. The effects of environmental acid on freshwater fish with particular reference to the softwater lakes in Ontario and the modifying effects of heavy metals. A literature review. Can.Techn.Rept.Fish.Aquat.Sci., (999).

This review examines the physiology of acid stress and the toxic effects of selected heavy metals in fish. Acid and metal stress may occur simultaneously in some Ontario softwater lakes due to atmospheric deposition and the leaching of bedrock and sediments. Fundamentals of normal acid-base regulation and its relationship to ionoregulation in fish are reviewed and updated. Toxic effects of low environmental pH are examined, and at pH values presently found in the field failure of ionoregulation appears to be the primary toxic response, at least in acute exposures. At more extreme pH's seldom encountered in the wild, anoxia and acid-base disturbance predominate.

The toxic effects of metals enriched in acid waters (Al, Cd, Cu, Pb, Mn, Ni, Zn) are briefly reviewed. Concentrations of these metals at present are generally below Great Lakes water quality objectives but their physiological effects at low pH are little known and possibly significant. The dilute nature of acidified Shield lakes suggests that the toxic effects of both stressors will be maximized especially since waterborne calcium, an important moderator of toxicity of both acid and metals, is scarce. Possible areas of synergism between acid and metals are outlined.

Although mortalities of mature fish are occasionally seen, the critical population response observed in the field is failure of reproduction. To date the relative importance of either acidity, metals, or their interaction in causing reproductive failure has not been delineated.

1981 - Use of blood lead and erythrocyte δ-amino levulinic acid dehydratase activity to detect lead exposure of fish populations. Proc.IAWPR.Pre-Conf.Symp.Ecotoxicology, Toronto, May, 1980:17-21.

The measurement of blood lead concentrations and inhibition of erythrocyte δ-amino levulinic acid dehydratase activity (ALA-D) has been used successfully to diagnose lead exposure in human populations. While blood lead is one of the best indicators of lead exposure, its measurement is expensive, time consuming, subject to bias through contamination and requires highly skilled personnel. The advantages of assaying ALA-D activity are those of cost, speed, sample size and simplicity. Since most organisms possess this enzyme in a variety of tissues, and since its activity is inhibited only by lead, there is potentially a large variety of aquatic species that may be used to monitor 'biologically available' lead in aquatic

HODSON, P.V.(cont.)

ecosystems. Sessile and migratory species could integrate short-term fluctuations in waterborne lead and provide data on spatial and temporal variations.

Fish are convenient organisms to sample and fish blood is a particularly rich source of ALA-D. Laboratory experiments have defined the optimum conditions for blood sampling and assaying ALA-D activity as well as the strong negative correlation between blood lead concentrations and ALA-D activity and between waterborne lead concentrations and ALA-D activity. Other toxic metals (e.g. Cu, Hg, Zn, Cd) and PCB's do not inhibit ALA-D, and factors that increase lead toxicity (e.g. decreased environmental pH) also increase lead uptake and the inhibition of ALA-D. Consequently, ALA-D activity provides a measure of both exposure and effect. Species variation in rates of lead uptake allows a selection of a suitable monitoring species for a given situation.

Preliminary surveys of Lake Ontario fish populations indicate that monitoring of ALA-D activity is technically simple and straightforward, the assay is much cheaper and faster than blood lead or whole body lead analyses, and activity is correlated to other measures of lead in fish.

1981 - with BLUNT, B.R. Temperature-induced changes in pentachlorophenol chronic toxicity to early life stages of rainbow trout. Aquat.Toxicol., 1:113-127.

Temperature was a controlling factor in pentachlorophenol (PCP) toxicity to rainbow trout (Salmo gairdneri). Eggs of trout exposed to PCP from fertilization to hatch showed elevated mortality and reduced weight at hatch. The effects on hatch weight were greatest in the cold regime (6°C) compared to the warm (10°C). Continued PCP exposure after hatch resulted in significantly elevated mortality, reduced growth rates and reduced yolk sac resorption efficiency, and these effects were again greatest in the cold regime (6°C) compared to the warm (15°C). In contrast, during 4 wk of feeding after yolk sac resorption, PCP-induced mortality was unaffected by temperature but growth rates were reduced to the greatest extent in the warm regime (20°C) compared to the cold (12°C). The potential biomass of 1,000 newly fertilized eggs at hatch, after yolk sac resorption, and after 4 wk of feeding was calculated from observed mortality and wet weights. The overall production of fish in the warm regime was reduced relative to controls at estimated threshold PCP concentrations of about 10 µg/l. In contrast, final biomass of fish in a cold regime was higher than control biomass at 10 µg/l and the estimated threshold of adverse effect was 20 µg/l. Although fish in a warm regime appeared to be affected at a lower concentration of PCP than those in the cold regime, the overall response to the highest PCP concentration was similar. Trout exposed to PCP during the egg stage were far more sensitive to PCP than were those only exposed after hatch.

1982 - DEMAYO, A., TAYLOR, M.C., TAYLOR, K.W., & HODSON, P.V. Toxic effects of lead and lead compounds on human health, aquatic life, wildlife plants, and livestock. In; P.C.STRAUB(ed.), Critical Reviews in Environmental Control:257-305. CRC Press. ISSN 0007-8999.

HODSON, P.V.(cont.)

1982 - HILTON, J.W., HODSON, P.V., & SLINGER, S.J. Absorption, distribution, half-life and possible routes of elimination of dietary selenium in juvenile rainbow trout (Salmo gairdneri). Comp.Biochem.Physiol. 71C:49-55.

The influence of different levels of dietary selenium on the metabolism of selenium in rainbow trout was studied using ^{75}Se as an indicator.

Gastric absorption of selenium by the trout appeared to be very efficient.

Highest tissue concentrations of selenium were noted in the liver and kidney.

Blood did not concentrate selenium and the plasma was the major transport medium.

The liver and kidney appeared to be involved in selenium excretion based on high tissue concentrations and variations in half-lives with selenium loading.

The biological half-life of selenium in the tissues decreased with increased selenium loading except in the liver, which at toxic dietary selenium concentrations became longer, suggesting a rate-limiting metabolic transformation of selenium for excretion in this organ.

1982 - with DIXON, D.G., SPRY, D.J., WHITTLE, D.M., & SPRAGUE, J.B. Effect of growth rate and size of fish on rate of intoxication by waterborne lead. Can.J.Fish.Aquat.Sci., 39:1243-1251.

Three experiments were undertaken to test the null hypotheses that increasing fish size and growth rate do not increase the rate of intoxication of fish by lead. The first experiment demonstrated that there were no significant correlations between weight of fish and either whole-body or blood lead concentrations in feral lake trout (Salvelinus namaycush). The whole-body lead concentration of rainbow smelt (Osmerus mordax) was, however, negatively correlated to wet weight.

During the second experiment, an 8-d laboratory exposure of rainbow trout (Salmo gairdneri) to 100 µg/L of total waterborne lead caused a greater uptake of lead by opercular bone in small fish than in larger fish. No relationship was apparent between fish weight and uptake of lead by blood.

Chronic exposure of juvenile rainbow trout to lead results in the development of black tails, a sympton of neurotoxicity. The final experiment related the incidence and prevalence of black tails to size and growth rate (ration level) of juvenile rainbow trout chronically exposed to 543 µg/L of total waterborne lead starting with the sac-fry stage. At weights below a common threshold size of 1.5 - 2.5 g, no black tails occured; above this threshold the incidence of black tails was a function of growth rate, i.e. the rate at which the fish reached the threshold size. The prevalence of black tails was always less in slowly growing fish.

These experiments demonstrated that the rate of intoxication by lead, as indicated by uptake rates into tissues and the incidence and prevalence of a symptom of neurotoxicity, did not increase with fish size, but rather with growth rate.

HODSON, P.V.(cont.)

1983 - SIPPEL, A.J.A., GERACI, J.R., & HODSON, P.V. Histopathological and physiological responses of rainbow trout (Salmo gairdneri Richardson) to sublethal levels of lead. Wat.Res., 17(9):1115-1118.

Rainbow trout (Salmo gairdneri) were exposed to sublethal levels of water-borne or dietary lead for 32 weeks. The study included a histopathological assessment of all organs, examination of red cell morphology, and a comparison of oxygen consumption in liver homogenates from exposed and control fish. No effects of lead toxicity were noted in these parameters. The most sensitive and reliable indicator of lead toxicity was the development of black tails and spinal curvature. These changes were observed in 30 percent of trout exposed to 120 ± 31 $\mu g.Pb.1^{-1}$ of waterborne lead after 30 weeks. No other effects of lead toxicity were noted.

1983 - DIXON, D.G., HODSON, P.V., & KAISER, K.L.E. The use of LD50 determination by intraperitoneal injection as a rapid method for initial estimates of pollutant toxicity to fish. Can.Techn.Rept. Fish.Aquat.Sci., (1151):157-160.

A useful screening procedure for assessing the hazard to fish of xenobiotic compounds is the use of quantitative structure-activity relationships. This approach requires rapid techniques for the measurement of relative toxicity of large numbers of compounds. This paper assesses the efficacy of LD50s measured by intraperitoneal injection (IPI) relative t0 oral injection (OI) and aqueous exposure (AE). A very strong positive linear correlation was observed between LD50s measured by IPI and OI for chlorobenzenes and para-substituted phenols. The LD50s by IPI were slightly lower due to faster uptake into the blood, as shown by studies with radio-labelled compounds. A strong curvilinear correlation of IPI LD50s to AE LC50s was observed for para-substituted phenols. IPI represents a rapid and inexpensive method for dosing fish to toxicity tests and the results represent toxicity as measured by alternative methods.

1983 - with HILTON, J.W. The nutritional requirements and toxicity to fish of dietary and waterborne selenium. In; R.HALLBERG(ed.), Environmental Geochemistry, Ecol.Bull. (Stockholm), 35:335-340.

Selenium is found throughout aquatic ecosystems but generally at very low concentrations. However, there are examples of aquatic ecosystems affected by industrial activity that have selenium concentrations at 5-100 times those found in clean areas. Therefore it is conceivable that there could be both inadequate and excessive levels of selenium in aquatic environments. This paper reviews new and published data to show that:

1. selenium is a nutrient for freshwater fish but, at levels observed in the water and food chain, deficiencies are unlikely to occur.

2. dietary selenium is relatively more toxic than waterborne selenium and dietary toxicity to fish is observed at concentrations close to those of food chain organisms;

HODSON, P.V.(cont.)

3. uptake of selenium from the diet appears very efficient and independent of dietary loading, but bioconcentration factors are limited at high dietary loadings by active excretion processes;

4. uptake of selenium from the water appears very efficient at low waterborne concentrations but bioconcentration factors at high waterborne concentrations appear limited by saturation of gill absorption processes. Elimination rates are passive so that bioconcentration factors are a function of uptake rates rather than elimination rates; and

5. the tissue distribution of selenium varies with exposure concentration because the selenium elimination rates of liver tissue decrease as exposure increases.

We speculate that waterborne selenium is stored predominantly in the inorganic form whereas dietary selenium may be metabolized and stored as an organic form. As such, it may be more toxic but more easily excreted than selenium taken up from water.

1983 - with BLUNT, B.R., & McGAW, S. The effect of fluctuating lead exposure on lead uptake by rainbow trout (*Salmo gairdneri*). Can.Techn.Rept.Fish.Aquat.Sci., (1151):161-163.

Contaminant concentrations in aquatic ecosystems vary spatially and temporally, so that surveillance data exhibit a log-normal distribution, i.e., the majority of measurements are low but a few are quite high. Contaminant concentrations in fish represent the balance between uptake and excretion. Therefore, contaminants that are taken up quickly but excreted slowly should accumulate in fish at concentrations reflecting the highest exposure concentrations rather than the means of exposure concentrations. To test this prediction, blood lead concentrations of rainbow trout were measured after 20-day exposures to waterborne lead concentrations that fluctuated about a fixed log mean. Four levels of exposure variability were used; a lead exposure characterized by wide fluctuations was expected to cause greater lead uptake by trout than the equivalent exposure with less variability.

The results were best described by the following equation: $\log_{10}$ blood lead concentration (μg/L) - 0.842 + $\log_{10}$ waterborne lead (μg/L) + 0.02148 x Coefficient of Variation of waterborne lead. Increasing lead concentration and increasing variability of waterborne concentrations increased lead uptake by trout. Therefore, brief violations of water quality objectives may cause a greater toxicity to fish than would be expected from estimates of average exposure concentrations.

1983 - with BLUNT, B.R., & WHITTLE, D.M. The suitability of a biochemical method for assessing the exposure of feral fish to lead. In; *Aquatic Toxicology and Hazard Assessment*. Proc.6th.ASTM.Symp.Aquat. Toxicol., STP 802:389-405.

A variety of biochemical techniques have been used to assess the response of fish to contaminants. These techniques may provide valuable tools for determining the degree of impact on real fish populations of contaminant exposure, and for identifying areas of contamination. Many of these techniques have not proven useful because

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they were not sensible, sensitive or specific. This paper reviews the use of erythrocyte δ-amino levulinic acid dehydratase (ALA-D) activity to indicate lead exposure of fish, both in the laboratory and in field surveys of Great Lakes fish. The enzyme has proven to be a reliable tool in laboratory studies of lead effects on rainbow trout (Salmo gairdneri). The field survey demonstrated that ALA-D activity is a suitable indicator of lead exposure of lake trout (Salvelinus namaycush) but that more research is required to confirm its application to other species.

1983 - with BLUNT, B.R., BORGEMANN, U., MINNS, C.K., & McGAW, S. Effect of fluctuating lead exposures on lead accumulation by rainbow trout (Salmo gairdneri). Environm.Toxicol.Chem., 2:225-238.

Contaminant concentrations in aquatic ecosystems vary spatially and temporally, so that surveillance data exhibit a log-normal distribution, i.e., the majority of measurements are low but a few are quite high. These data are best characterized by geometric means. Contaminants that are taken up quickly but excreted slowly should accumulate in fish at concentrations that reflect the highest exposure rather than the geometric mean exposure. To confirm this prediction, blood lead concentrations of rainbow trout were measured after 20-d exposures to concentrations of waterborne lead that fluctuated about a fixed geometric mean. Four levels of exposure variability were used. A lead exposure characterized by wide fluctuations was expected to cause greater lead uptake by trout than the equivalent exposure with less variability. Lead accumulation was best described by the following equation: $\log_{10}$ blood lead concentration (μg/L) = 0.814 + $0.999\log_{10}$ waterborne lead (μg/L) + 1.335 x standard deviation of $\log_{10}$ waterborne lead. Increasing lead concentrations and increasing variability of waterborne concentrations increased lead accumulation by trout. These results were accurately predicted by a simple one-compartment model of contaminant kinetics in fish. Applying this model to other contaminants and to hypothetical exposure regimes demonstrated that high depuration rate constants increase the importance of exposures over the previous 24 h. This analysis also demonstrated that arithmetic mean exposures were a better way of describing contaminant accumulation by fish than were geometric mean exposures. Therefore, brief (24 h) violations of water quality criteria may cause a greater toxicity to fish than would be expected from simple estimates of the geometric mean concentrations in water. Water quality surveillance programs must be designed to accurately describe both contaminant variance and the arithmetic mean concentration.

1983 - HILTON, J.W., HODSON, P.V., BRAUN, H.E., LEATHERLAND, J.L., & SLINGER, S.J. Contaminant accumulation and physiological response to rainbow trout (Salmo gairdneri) reared on naturally contaminated diets. Can.J.Fish.Aquat.Sci., 40:1987-1994.

Juvenile rainbow trout were reared for 24 wk practical-type diets formulated with fish meals derived from coho salmon (Oncorhynchus kisutch) taken from Lake Michigan, Lake Ontario, and the Pacific

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Ocean. Levels of contaminants (DDT, chlordane, dieldrin, mirex, and PCBs) increased 10-fold from control and Pacific Ocean salmon-based diets to Lake Ontario salmon-based diets. Rainbow trout accumulated contaminants in direct proportion to dietary levels. However, there were no significant differences in the final body weights, feed to gain ratios, or mortality rates of the trout reared on the different test diets. No signs of abnormal behaviour or any indication of histopathological abnormalities were observed in any of the fish. There were no signs of thyroid hyperplasia or any significant decline in serum T_3 or T_4 levels with increasing dietary contaminant levels. Therefore, rainbow trout do not appear to have been affected by the uptake and accumulation of contaminants. However, the trout did not appear to regulate their body burden of contaminants; this ultimately could prove to be toxic and may adversely affect the ability of these fish to reproduce and survive. The final concentrations of mirex and PCBs in the Lake Ontario-fed fish exceeded the allowed limits to protect human health; therefore, fish meals produced from Lake Ontario salmon are unsuitable as a source of feed for aquaculture of rainbow trout intended for human consumption.

1983 - HILTON, J.W., & HODSON, P.V. Effect of increased dietary carbohydrate on selenium metabolism and toxicity in rainbow trout (*Salmo gairdneri*). J.Nutrit., 113:1241-1248.

Juvenile trout were reared on either a high available carbohydrate (HC) or low available carbohydrate (LC) diet supplemented with from 0 to 10 μg selenium per gram of diet for 16 weeks, to determine if excess liver glycogen deposition affected the metabolism and toxicity of dietary selenium. Trout reared on the HC diet with 10 μg selenium per gram diet first demonstrated signs of selenosis and had significantly higher ($P < 0.05$) liver selenium levels than trout reared on the LC diet with 10 μg selenium per gram diet after 16 weeks, indicating that excess dietary carbohydrate enhances dietary selenium toxicity in trout. The mechanism of the interaction is unclear since neither selenium elimination rates nor carcass and kidney selenium levels were affected by the dietary carbohydrate level. Trout reared on high dietary selenium diets (10 μg/g) had an increased incidence of renal calcinosis. In addition, liver copper levels were significantly affected by both dietary selenium and liver glycogen content indicating a significant copper-selenium and copper-glycogen interaction in trout. The development of renal calcinosis and the copper interactions suggest a variety of toxic effects of selenium on trout that may all be responsible for the observed changes in growth and feed efficiency.

1983 - with BORGMANN, U., & MINNS, C.K. The effects of fluctuating concentrations of waterborne contaminants on their uptake by fish - implications for water quality monitoring. In; Chemicals in the Environment: Chemical Testing and Hazard Ranking - the Interaction between Science and Administration:259-265. Proc.Internat.Symp., Denmark, October, 1982.

HODSON, P.V.(cont.)

1984 - with BLUNT, B.R., & WHITTLE, D.M. Monitoring lead exposure of fish. In; V.W.CAIRNS, P.V.HODSON, & J.O.NRIAGU(eds.), Contaminant Effects on Fisheries:87-98. John Wiley & Sons. ISBN 0-471-88014-0.

Measurements of the inhibition of erythrocyte δ-amino levulinic acid dehydratase (ALA-D) activity of fish are inexpensive, technically simple, rapid, and specific for lead. The extent of inhibition is strongly linked to inorganic lead exposure and to the neurotoxic effects of lead. There are three problems with the measurement of ALA-D activity. First, the enzyme is inhibited by blood lead, which in turn varies with lead exposure; hence ALA-D activity is an indirect, or secondary, indicator of lead exposure. Second, ALA-D activity is inhibited only slightly by alkyllead compounds; therefore activity will not reflect exposure to these compounds. Third, Monitoring of ALA-D activity of feral fish has proven only partially successful because: (1) it is necessary to describe the optimum conditions for assaying activity in each species examined; (2) migration of fish confounds clear-cut comparisons between contaminated and uncontaminated sites; (3) contamination by inorganic lead is rarely severe enough to provide a good test of the ALA-D method. Nevertheless, field trials are promising and further research is warranted to realize the advantages of this technique.

Other possible indicators of lead exposure are assays of blood porphyrins. While these methods are suitable in human toxicology, we are unable to find high porphyrin levels in the blood of control or lead-exposed rainbow trout. Therefore the effect of lead on hemoglobin metabolism in fish may differ from that in humans.

1984 - with DIXON, D.G., & KAiSER, K.L.E. Lethal dose versus lethal concentration as indicator of contaminant toxicity to fish. In; K.L.E.KAISER(ed.), QSAR in Environmental Toxicology:179-187. D.Reidel Publ.Co. ISBN 90-277-1776-1.

Median lethal dose determinations by intraperitoneal injection (IPLD50) provide a rapid and reliable indication of the lethal effects of chemicals on fish. The IPLD50s are correlated with oral lethal dose (OILD50) as well as aqueous lethal concentration (LC50), the traditional measure of toxicity. The speed and efficiency of toxicity testing by IPLD50 makes it a valuable tool for structure-activity studies of toxic substances.

1984 - with WHITTLE, D.M., & HALLETT, D.J. Selenium contamination of the Great Lakes and its potential effects on aquatic biota. In; J.O.NRIAGU & M.S.SIMMONS(eds.), Toxic Contaminants in the Great Lakes. John Wiley & Sons, Advances Environm.Sci.Technol., (14):371-391. ISBN 0-471-89087-1.

Selenium concentrations in the Great Lakes are obviously elevated in some areas due to anthropogenic inputs. Given the potential adverse effects on fish of selenium accumulation in benthic food chains, it is important to better document existing sources, loading rates, and sites of contamination. In particular, the degree of contamination of industrial harbors and Georgian Bay needs to be described. The cause of selenium accumulation by benthos and the role of bacterial transformations in the accumulation and its subsequent toxicity to bottom-feeding fish needs more research. This would aid in understanding the factors that will foster or inhibit effects on fish, particularly sediment conditions that favor contamination of benthos.

1984 - with WHITTLE, D.M., WONG, P.T.S., BORGMANN, U., THOMAS, R.L., CHAU, Y.K., NRIAGU, J.O. & HALLETT, D.J. Lead contamination of the Great Lakes and its potential effects on aquatic biota. In; J.O.NRIAGU & M.S.SIMMONS(eds.), Toxic Contaminants in the Great Lakes. John Wiley & Sons, Advances Environm.Sci.Technol., (14):335-369. ISBN 0-471-89087-1.

This review has demonstrated that much is known of lead in the Great Lakes and its potential inpacts on aquatic biota; this information is summarized by a conceptual diagram of lead in a lake ecosystem. Overall, lead input to the Great Lakes is considerably above expected 'natural' inputs due to human activities, and much of this input is inorganic lead from the atmosphere. However, due to complexation of inorganic lead, it appears that significant concentrations of biologically available 'free' lead will be found only near point sources. This should restrict the negative impacts of waterborne lead to relatively small areas of the lakes. However, lead concentrations in sediments are elevated over a wide area due to continual atmospheric loadings and the movement and settling of contaminated particulates from point sources. The observations of lead methylation by sediment bacteria, rapid uptake of alkyl lead compounds by aquatic biota, and the greater contamination of benthic-feeding fish relative to pelagic-feeding fish suggests that the impacts of lead may be somewhat more widespread than expected. A true understanding of impact will only arrive from research to address the questions outlined.

1984 - Contaminant Effects on Fisheries. See under CAIRNS, V.W.

1984 - DIXON, D.G., HODSON, P.V., & KAISER, K.L.E. The use of rapid biochemical indicators of toxicant stress to generate biological data bases for QSAR. In; K.L.E.KAISER(ed.), QSAR in Environmental Toxicology:67-73. D.Reidel Publ.Co. ISBN 90-277-1776-1.

The assay of serum sorbitol dehydrogenase and plasma leucine aminonaphthylamidase activities to indicate liver damage of toxicant to rainbow trout (*Salmo gairdneri*) was assessed using para-methylphenol (para-cresol) as a model toxicant. Both tests appear to be useful indicators for the rapid assessment of toxicant effects on fish.

1984 - KAISER, K.L.E., DIXON, D.G., & HODSON, P.V. QSAR studies on chlorophenols, chlorobenzenes and para-substituted phenols. In; K.L.E.KAiSER(ed.), QSAR in Environmental Toxicology:189-206. D.Reidel Publ.Co. ISBN 90-277-1776-1.

The acute toxicities of chlorophenols (CP's), chlorobenzenes (CB's) and para-substituted phenols (PP's) to rainbow trout (*Salmo*

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gairdneri) as intraperitoneal injection lethality, serum sorbitol dehydrogenase activity, and 96-hr lethal concentration are investigated in terms of quantitative structure-activity correlations (QSARs). The effects of CP's and CB's are primarily related to the chemicals' octanol/water partition coefficients (log P). The slopes of the QSARs of CP's for rainbow trout are nearly parallel to those of acute and semichronic CP toxicities to bluegill (Lepomis macrochirus), guppy (Poecilia reticulata), waterflea (Daphnia magna) , and the marine organism Photobacterium phosphoreum, indicating similar mechanisms of toxic effects. The toxicities of PP's are dependent on both log P and other molecular descriptors, such as molar refractivity and field and resonance constants of the para-substituents.

1984 - with DIXON, D.G., & KAISER, K.L.E. The measurement of median lethal doses (LD50s) as a rapid indication of contaminant toxicity to fish. Environm.Toxicol.Chem., 3:243-254.

A new method was developed to rapidly measure the toxicity of contaminants to fish over 96 h. The method is the measurement of median lethal doses by intraperitoneal injection (IP.LD_{50}). Contaminants are dissolved in five percent ethanol in saline or in cod-liver oil and injected at a rate of 1.0 ml per 100 g of fish.

The results of parallel bioassays to measure toxicity by oral intubation (OI.LD_{50}) or aqueous exposure (LC_{50}) were closely linked ti IP.LD_{50} values. The coefficient of determination (r^2) for a linear regression between IP.LD_{50} and OI.LD_{50} values was 0.99. In contrast, the r^2 between IP.LD_{50} and LC_{50} values was lower (0.44) and the regression curvilinear. However, r^2 improved to 0.82 when LD_{50} values were divided by the logarithm of the octanol-water partition coefficient (log P). Therefore, some of the differences in toxicity between chemicals may be due to interactions between their lipid (or water) solubilities and their rate of uptake by fish.

The IP.LD_{50} values of five chemicals varied with the carrier used; toxicity was lower for the oil carrier compared to injections with five percent ethanol in saline. The magnitude of the difference varied with the chemicals tested, so that the two measures of toxicity did not appear to be related. However, the relationships again improved when the IP.LD_{50} (oil) was divided by log P.

The measurement of IP.LD_{50} values was faster, simpler and less expensive than traditional LC_{50} bioassays. The use of IP.LD_{50} values to screen chemicals for their relative toxicity to fish will save time and money without any real loss in the relevance of conclusions. We propose their use for research on environmental quantitative structure-activity relationships.

1985 - McCARTY, L.S., HODSON, P.V., CRAIG, G.R., & KAISER, K.L.E. The use of quantitative structure-activity relationships to predict the acute and chronic toxicities of organic chemicals to fish. Environm.Toxicol.Chem., 4:595-606.

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Quantitative structure-activity relationships (QSARs) predict bioconcentration and acute toxicity to fish of chemicals causing narcosis on the basis of hydrophobicity, as measured by the octanol/water partition coefficient (K_{ow}). Since the development of water quality objectives to protect fish is limited by the availability of suitable chronic toxicity data, we applied the QSAR concept to published and unpublished data to determine (a) whether chronic toxicity could be related to K_{ow} and (b) whether application factors are constant, i.e. , whether QSARs for acute and chronic toxicity are parallel. Our conclusions are as follows: (1) A QSAR, based on hydrophobicity (log K_{ow}), appears to exist for the chronic toxicity of organic chemicals inducing acute toxicity by narcosis. Although not definite, this QSAR was not parallel to that for acute toxicity and does not appear to support the concept of constant application factors. (2) Log K_{ow} has a major effect on the rate of net bioconcentration of certain organic chemicals; therefore, the relationship of toxicity to log K_{ow} may not be linear if exposure times are fixed, as very different amounts of toxicants will be taken up over a fixed time period. (3) As a result of the effect of log K_{ow} on bioconcentration rates, many toxicity tests of relatively short, fixed duration may underestimate toxicity of some hydrophobic organic compounds, especially those exhibiting high log K_{ow} values. Hence, water quality objectives developed directly from this data, without appropriate compensation, may not be restrictive enough. (4) To increase the accuracy, comparability and applicability of aquatic bioassay test results, especially for compounds of widely differing hydrophobicity, standard tests should be redesigned. For example, it may be more accurate if the exposure or dosage for the test organism is expressed as a summation of the periodically calculated product of body toxicant level and time up to predetermined summation values.

1985 - A comparison of the acute toxicity of chemicals to fish, rats and mice. J.Appl.Toxicol., 5(4) :220-226.

The acute toxicity of chemicals to rainbow trout, as shown by intraperitoneal injections (IP LD_{50}), oral dosing (oral LD_{50}) and aqueous exposure (LC_{50}) was compared with published values for IP LD_{50}S and oral LD_{50}s of mice and rats. The method of comparison was by simple linear regression analyses of log-transformed data, modified to recognize that X (fish toxicity) was neither fixed nor measured without error.

Within-species comparisons demonstrated very strong linear correlations (r=0.866-0.998) between IP and oral LD_{50}s. Variability was least for the fish data since it was all generated in one laboratory.

Comparisons between species of IP and oral LD_{50}s gave correlation coefficients ranging from 0.59 to 0.95 with the majority over 0.80. Correlations were best (r=0.83-0.94) between fish LD_{50}s and rat and mice IP LD_{50}s. Correlations were poorest between fish and mammalian oral LD_{50}s (r=0.59-0.66) because the sample sizes and the ranges of values were very small. In all cases, the slopes were close to, or equalled, one.

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Comparisons of fish LC_{50}s to fish or mammalian LD_{50}s were not as successful. Correlation coefficients ranged from 0.19 to 0.83. Presumably the cause was the aqueous exposure. Interactions of the chemicals with water (e.g. dissociation) and with lipid membranes (partitioning) should cause considerable variations in uptake efficiency. However, adjustments of LC_{50}s for dissociation constants and partition coefficients did not improve these correlations, probably because there were few chemicals for which all data were available.

These comparisons demonstrate a potential for a wider use of surrogate species in toxicity testing and for adapting existing data from mammalian toxicology to aquatic hazard assessments.

1985 - (Comments on 'Need for development of epidemiology for chemically induced diseases in fish in Canada' by M.G.Gilbertson). Can.J.Fish.Aquat.Sci., 42:1226-1227.

1985 - with SPRY, D.J. Effect of sulfite dechlorination on the accumulation of waterborne lead by rainbow trout (Salmo gairdneri). Can.J.Fish.Aquat.Sci., 42:841-844.

Chlorine can be removed from laboratory water supplies by reduction with sodium sulfite, but sulfite complexation of metals may bias aquatic toxicity tests. We tested the effect of waterborne sulfite on the accumulation of waterborne lead by rainbow trout (Salmo gairdneri). After 96 h, the blood levels of trout exposed to both 100 μg lead/L and 440 μg sodium sulfite/L were lower than those exposed to lead alone. The highest level of sodium sulfite having no effect on blood lead was 20 μg/L. The addition of 200-300 μg sodium sulfite/L to our water supply after charcoal filtration removed residual chlorine levels rapidly and completely. This reaction, and other possible reactions with organic matter, always reduced measurable sulfite levels to less than 1 μg/L (limit of detection), a level much lower than those tested. Hence, sulfite dechlorination should not interfere with metal bioassays.

1985 - DIXON, D.G., HODSON, P.V., KLAVERKAMP, J.F., LLOYD, K.M., & ROBERTS, J.R. The role of biochemical indicators in the assessment of ecosystem health - their development and validation. Environm. Secretariat, Ntnl.Res.Counc.Can., Publ., (24371).

The pollution of the aquatic environment by industrial organic chemicals as a result of man's activities has long been recognized. Approaches used to define the impact of contaminants on aquatic ecosystems have classically involved laboratory experiments and, to a lesser extent, field observations on populations. To date, however, there are no available methods that are widely accepted and reliable for determining the degree of impact of chemical contaminants on aquatic organisms, and the extent of these impacts thus remains essentially undefined.

This document presents an argument for monitoring the biochemical responses of individual organisms to toxic chemicals as a more suitable method of assessing ecosystem health than traditional biological monitoring of populations. The systematic development of biochemical diagnostic tests and their application to environmental management are advocated in order to define a more efficient and realistic strategy for assessing and managing the effects of toxic chemicals in aquatic ecosystems. An analysis of 15 biochemical indicators of ecosystem health in terms of present state of development and future prospects for ecosystem health assessment led to the conclusion that most of the tests, despite showing promise, are still in an elementary stage of development. Specific areas where further research is warranted and could be productive are therefore recommended.

1985 - DIXON, D.G., HILL, C.E.A., HODSON, P.V., KEMPE, E.J., & KAISER, K.L.E. Plasma leucine aminonaphthylamidase as an indicator of acute sublethal toxicant stress in rainbow trout. Environm. Toxicol.Chem., 4:789-796.

Leucine aminonaphthylamidase (LAN) is a lysosomal enzyme that appears in blood plasma after cell death. Levels of plasma LAN (PLAN) were assayed to quantify toxicant stress in rainbow trout in a series of experiments. Blood samples were taken from groups of fish weighing 80 to 100 g following intraperitoneal (i.p.) and/or waterborne exposure to p-methylphenol (PMP) or carbon tetrachloride (CCl_4).

The duration of postinjection holding significantly affected PLAN activity in control and PMP-dosed rainbow trout; the largest increase occured after 96 h. There were significant correlations between dose and PLAN activity after both PMP and CCl_4 injection. PLAN levels of fish injected with PMP at doses of 0.075 to 0.75 of the 96-h i.p. LD50 were elevated by 27 to 63 percent relative to controls 96 h after injection. PLAN levels of fish injected with CCl_4, at doses of 0.18 to 0.79 of the i.p. LD50 were elevated by 38 to 135 percent relative to controls 48 h after injection. Exposure of fish to a waterborne concentration of 0.028 mM PMP (0.41 96-h LC50) significantly increased PLAN activity after 48, 96 and 192 h; activities increased by 38 to 87 percent relative to controls. Elevated PLAN activity was strongly correlated with decreased plasma protein levels. The temperature and duration of plasma storage affected the measured PLAN activity of control and PMP-dosed rainbow trout. While diet modified PLAN activity, the gender of immature fish had no effect.

Hepatic lesions visible by light microscope were observed with waterborne PMP exposure; parenchymatous edema was closely associated with increased liver somatic index. There were, however, no visible lesions or changes in the index associated with the pulse i.p. doses of PMP and CCl_4. In these cases, biochemical lesions preceded any evidence of histopathology.

1985 - BOLS, N.C., BOLISKA, S.A., DIXON, D.G., HODSON, P.V., & KAISER, K.L.E. The use of fish cell cultures as an indication of contaminant toxicity to fish. Aquat.Toxicol., 6:147-155.

The cytotoxicity of 12 chemicals to rainbow trout cells (RTG-2) was determined in culture. The indicator of cytotoxicity was the inability of cells to attach to a growth surface after chemical

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exposure. From most toxic to least toxic, these chemicals were pentachlorophenol, p-methylaminophenol, 2,4-dichlorophenol, p-chlorophenol, p-cyanophenol, p-nitrophenol, benzene, p-methylphenol, aniline, phenol, p-methoxyphenol, and 1,2,4-trichlorobenzene. The cytotoxicity of these compounds was found to be significantly correlated to their waterborne toxicity to rainbow trout.

1986 - with HILTON, J.W., & SLINGER, S.J. Accumulation of waterborne selenium by rainbow trout (*Salmo gairdneri*), eggs, fry and juveniles. Fish Physiol.Biochem., 1(4):187-196.

The effect of waterborne selenite levels on selenium accumulated by different developmental stages of rainbow trout (*Salmo gairdneri*) was studies using $^{75}SeO_3^{=}$ as a tracer. All stages readily accumulated selenium at both high and low concentrations, but the rate of accumulation increased as the trout developed from the egg to the juvenile feeding stage. The low rate of selenium accumulation by embryos seemed to be related more to a lack of gills than to the presence of a chorion. The bioconcentration factor (the ratio of tissue-to-water concentrations) declined in all groups with increased waterborne selenium levels; accumulation rates appeared limited by cell permeability. At low levels of waterborne selenium (0.4 μg/l), the total accumulated was small relative to existing body burdens and unlikely to contribute significantly to the nutritional requirement for selenium. High levels (45.6 μg/l), however, caused considerable selenium accumulation and may be sufficient to overcome the effects of low dietary selenium.

1986 - with BLUNT, B.R. The effect of time from hatch on the yolk conversion efficiency of rainbow trout, *Salmo gairdneri*. J.Fish Biol., 29:37-46.

The growth and development of rainbow trout, *Salmo gairdneri*, from hatch to first feeding depends upon the nutrients stored in the yolk sac. The efficiency (E) with which yolk can be converted to larval biomass is a useful measurement in chronic toxicity tests, and it can be simply estimated by comparing the gain in larval weight (L) to the loss in yolk weight (Y) at hatch (time 0) and at any time after hatch: $E=(L_1 - L_0)/(Y_0 - Y_1)$; E may be calculated on a wet or dry weight basis. Although the rates of weight change were constant for the first 15 days after hatch at 10.5°C, E was not. E increased from near 0 and approached a value of 2.1 on a wet weight basis or 0.70 on a dry weight basis after 5-8 days. The variability of E was also very high shortly after hatch, but declined and stabilized within 5-9 days. For toxicity testing, we recommend that E be measured 10-15 days posthatch to ensure precision with a minimum bias due to dissection error.

1986 - Water quality criteria and the need for biochemical monitoring of contaminant effects on aquatic ecosystems. In; B.T.HART(ed.), *Water Quality Management - Freshwater Ecotoxicity in Australia*:7-22. Wat.Stud.Centre, Chisholm Inst.Technol., Caulfield East, Australia.

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Water quality criteria protect the beneficial uses of water by limiting the occurence of toxic chemicals in aquatic ecosystems. However, there is no assurance that aquatic ecosystems will be unharmed simply because all criteria have been met. This uncertainty is due to problems in the development of criteria. Test species and exposure regimes are often inappropriate, little data exists on environmental interactions, and single species tests are used to protect multi-species systems. The application of criteria is hindered by poorly developed mixing zone concepts and there are few limitations on loading. As well, criteria have inherent limitations arising from a poor understanding of the ecosystems to be protected and an inability to predict or limit interactive toxicity, unexpected responses or the effects of unknown chemicals.

A useful solution to some of these problems is to examine aquatic ecosystems for specific responses to toxic chemicals and to then take corrective action. However, protection will not be achieved if whole ecosystem or population responses are monitored; the indicators are important toxic effects that represent real damage. Much more suitable indicators are the first biochemical effects of toxic chemicals in individual organisms. All chemical effects at the population or ecosystem level must start with a specific biochemical reaction in an individual. Diagnostic tests for these specific reactions provide sensitive, specific and early warning indicators that enable management of toxic chemicals before important losses of beneficial uses.

To implement this approach, research is needed on the mechanisms of chemical toxicity to identify useful diagnostic tests, and on the link between specific biochemical responses and real damage to aquatic ecosystems.

1986 - The effects on aquatic biota of exposure to lead. In; P.M.STOKES(ed.), Pathways, Cycling and Transformation of Lead in the Environment, Chapt.9. Roy.Soc.Can., Comm.Lead Environm. 415pp.

1) The concentrations of total waterborne lead that are toxic to aquatic biota range from about 4 to 500,000 g L^{-1}.
2) The most important causes of this variation include (a) water quality - organic and inorganic complexation, (b) the form of lead - Pb(II) versus Pb(IV), (c) species sensitivity, and (d) the age of the exposed organism.
3) Lead is readily accumulated by aquatic biota from water; accumulation from diet and sediments is less certain. Bioconcentration factors (the ratio of tissue to waterborne concentrations) decrease from 20,000 in algae to less than 1,000 in fish. Field studies confirm that lead concentrations are not biomagnified in food-chains.
4) Symptoms of lead exposure include lead accumulation, enzyme inhibition, anemia and deformities in fish, reduced rates of growth, reproduction and survival of invertebrates and fish, and reduced productivity of all biota.
5) Field studies of lead pollution in England, Sweden, the United States, Nova Scotia and the Great Lakes demonstrate that (a) lead concentrations in edible fortions of fish are often higher than the recommended limit for human health, (b) enzyme inhibition and other

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physiological changes typical of laboratory toxicity tests are readily observed, (c) populations of algae, benthos and fish may be reduced or completely eliminated, depending upon the severity of contamination, and (d) benthic fish species are more contaminated with lead than pelagic species.

6) Alkyllead compounds released during their manufacture are 10-20 times more toxic and 10 times more concentrated in biota than inorganic lead.

7) Of several research needs, the most important is the evaluation of the rate and effects of alkyllead compounds, particularly their entry into human food.

1986 - GIBBS, C.F., WANKOWSKI, J.W.J., LANGDON, J.S., HUMPHREY, J.D., ANDREWS, J.S., HODSON, P.V., FABRIS, J.G., & MURRAY, A.P. Investigations following a fish kill in Port Philip Bay, Victoria, during February, 1984. Victoria Fish Wildl.Serv., Techn.Rept., (63):30pp.

HOLMES, J.A.(under contract)

1984 - with WHILLANS, T.H. Historical review of Hamilton Harbour fisheries. Can.Techn.Rept.Fish.Aquat.Sci., (1257).

Historical relationships between the fisheries, habitat, exploitation and interspecific interactions are compared with present conditions to determine the feasibility of fisheries rehabilitation in Hamilton Harbour. Commercial catch records are analyzed for changes in fishing effort and relative abundance of species. These changes are correlated with changes in aquatic macrophytes, plankton, benthic invertebrates, bathymetry, bottom materials, and recreational fishing.

Lake trout, whitefish, and herring have been extirpated from the harbour It is probable that a substantial suitable deepwater habitat remains. However, this habitat is completely unavailable because of extremely poor water quality, in particular low levels of dissolved oxygen.

Extensive warmwater habitat has been lost. However, changes in the warmwater fish community have not been as dramatic. New habitat and improvements in the quality of remaining habitat would probably result in a substantial increase in warmwater fish populations in the harbour.

Based on current evidence, rehabilitation of the Hamilton Harbour fisheries would probably contribute to a revitalized whitefish and herring fishery in western Lake Ontario. It is unlikely that re-establishing lake trout in the harbour would have any direct effect on the western Lake Ontario fishery.

This study shows that fisheries rehabilitation is feasible in much of the harbour. It provides an historical data base for future management of Hamilton Harbour.

1986 - The impact of dredging and spoils disposal on Hamilton Harbour fisheries: implications for rehabilitation. Can.Techn.Rept. Fish.Aquat.Sci., (1498).

HOLMES, J.A. (cont.)

The impacts of dredging and spoils disposal on Great Lakes fish communities are reviewed. Changes in physical and chemical variables may alter the productivity of plankton, aquatic macrophytes, benthos, and fish depending on the timing and location of the operation. Many of these changes have short-term negative effects and therefore may be difficult to detect. Some impacts, such as the release and remobilization of contaminants from dredged sediments, have long-term fisheries implications requiring further investigation.

The limits and constraints imposed on fisheries rehabilitation efforts in Hamilton Harbour by dredging and spoils disposal operations are also assessed. Detailed accounts of the physical and chemical characteristics of the sediments, their movements, and historic, current, and future dredging and spoils disposal practices as they affect the fisheries in the harbour are provided. Spoils disposal in shallow nearshore areas were a serious degradative influence on the fisheries historically. Current dredging and disposal practices do not appear to be detrimental to primary or secondary productivity in the system. No negative effects are anticipated from future dredging operations provided they continue along the Hamilton waterfront. However, future spoils disposal in confined facilities may seriously impinge upon fisheries rehabilitation efforts, since the shallow water littoral areas are the most suitable for fisheries restoration and the disposal of dredge spoils.

HYATT, W.H.

1978 - Spatial distribution of nearshore fish in the vicinity of two thermal generating stations, Nanticoke and Douglas Point, on the Great Lakes. See under MINNS, C.K.

1979 - Considerations of entrainment of larval fish by a St.Clair River, Ontario, power plant. See under LESLIE. J.K.

1983 - Seine for sampling larval fish in shallow water. See under LESLIE, J.K.

1986 - with FITZSIMONS, J.D., KEIR, M.J., & WHITTLE, D.M. Biological tissue archive studies. Can.Techn.Rept.Fish.Aquat.Sci., (1497).

The Great Lakes Fisheries Research Branch has continuously archived fish tissue homogenates from the Canadian Great Lakes since 1978. Fish samples collected and analyzed for the annual Contaminants Surveillance Program have also been archived for future retrospective analysis of recently identified contaminants. Additional samples have been archived for experiments designed to define preservation and long-term storage conditions required to maintain the integrity of chlorinated hydrocarbon residues in biological tissues.

Samples have been stored at -20°C, -40°C, -80°C, and -196°C. Preservation treatments including prefreezing, and a stepped rate of freezing, have been studied. Some samples were oven-dried at +60°C, prior to storing at room temperature.

HYATT, W.H. (cont.)

Data indicate that freezing at -80°C was preferential to storage at the other temperatures studied. Prefreezing and a stepped rate of freezing did not produce significantly better storage conditions for sample integrity.

Radiolabelled PCB was used to measure the efficiencies of three extraction methods as compared to a biological material oxidizer. The efficiencies of all extraction methods studied appeared to be low when compared to the radiolabelled PCB level recovered with a biological material oxidizer. Other preservation techniques studied included formalin and hydrochloric acid treatments of fish tissue. These techniques were found not to be adequate methods to maintain the integrity of the samples with respect to chlorinated hydrocarbon residues.

JOHANNSSON, O.E.

1980 - Energy dynamics of the eutrophic chironomid *Chironomus plumosus f. semireductus* from the Bay of Quinte, Lake Ontario. Can.J.Fish. Aquat.Sci., 37:1254-1265.

Relationships between feeding rate, temperature, body size, and time of day were investigated and collated with seasonal assimilation efficiencies of *in situ* chironomids to construct a picture of chironomid energetics over the year. Temperature controlled feeding rate, and larval size and time of day exerted no effect. The temperature optimum plateaued between 22.0 and 24.5°C, decreasing logarithmically outside this range. Both assimilation efficiency (AE) and organic content of the food varied seasonally, but were not correlated. Periods of high AE corresponded with the latter part of *Melosira* or *Melosira-Stephanodiscus* blooms, while periods of low AE occured between diatom blooms and during the late summer blue-green bloom. Consequently, growth fluctuated throughout the year, being the result of interaction of temperature and AE. Anabolic processes dominated at AE greater than 3.5 percent. Maximum net growth efficiency (NGE) was attained when AE $\geq$6 percent and temperature $\geq$15°C. NGE was more sensitive to changes in AE than temperature. Instantaneous growth rate, however, was more sensitive to changes in temperature. Daily ingestion (mg) exceeded body weight by as much as 400-480 percent, which equals the sediment-processing capacity of freshwater detritivores.

1985 - with DERMOTT, R.M., FELDKAMP, R., & MOORE, J.E. Lake Ontario Long Term Biological Monitoring Program: report for 1981 and 1982. Can.Techn.Rept.Fish.Aquat.Sci., (1414).

The Bioindex, or Long Term Biological Monitoring Program, was developed to: 1) determine normal seasonal patterns and annual ranges of abundance, community structure, and when possible, productivity of the biological components - phytoplankton, zooplankton, and benthos; 2) relate the biological components to variations in the physical, nutrient, and biological environment; and 3) assess the adopted sampling strategy for long term monitoring.

The results from the first two years are presented and compared with historical data. Changes in abundance and community structure are compatable with the decreases in phosphorus loadings to the lake

JOHANNSSON, O.E.(cont.)

and continuing severe alewife predation. Seasonally weighted mean algal biomass in 1981, and 1982 was 50 percent lower than in 1970, while zooplankton abundance tripled. Benthic biomass fluctuated since the 1960s and indicate a slight decrease since 1968. Phytoplankton indicator species suggest a change from meso-eutrophic to meso-eutrophic/meso-oligotrophic conditions during this period.

It was concluded that the Bioindex sampling strategy is appropriate for long term monitoring. Improvements suggested include integrative sampling for all parameters, hypolimnetic zooplankton sampling and net calibration studies.

1985 - with DERMOTT, R.M., FELDKAMP, R., & MOORE, J.E. Lake Ontario Long Term Biological Monitoring Program: 1981, 1982 data base. Can.Data Rept.Fish.Aquat.Sci., (552).

The data bases from the first two years of the Lake Ontario Long Term Biological Monitoring Program are summarized.

JOHNSON, M.G.

1974 - Benthic macroinvertebrates of the St.Lawrence Great Lakes. See under COOK, D.G.

1974 - Production and productivity. In; R.O.BRINKHURST(ed.), The Benthos of Lakes:46-64. MacMillan Press, London, England.

The traditional use of total dissolved solids and mean depth seems appropriate. Ryder's morphoedaphic index, total dissolved solids divided by mean depth, proved to be reasonably successful in the prediction of fish yields (probably a much better index of fish production than standing stocks) but it has not been related to bottom fauna. Area may have additional value in the attempt to incorporate the effect of diminishing enrichment of the profundal zone of a lake from the littoral zone, and allochthonous import which would be expected with increasing lake area.

1976 - SWISS, J.J., & JOHNSON, M.G. Energy dynamics of two benthic crustaceans in relation to diet. J.Fish.Res.Bd.Can., 33:2544-2550.

Energy dynamics were studied in Asellus racovitzai (Crustacea: Isopoda) and Gammarus fasciatus (Crustacea: Amphipoda) fed various selected algal species (Cyanophyta - Oscillatoria sp., Anabaena flos-aquae, Anacystis nidulans, Microcystis aeruginosa; Chlorophyta - Chlorella ellipsoidea, Scenedesmus dimorphus, Ankistrodesmus falcatus) and lake sediments. Calculations of growth, production, assimilation, and growth efficiency were made from measurements of weight change, respiration rate, and caloric content of experimental animals. Although growth rate, production, and growth efficiency were often highest in animals fed green algae, differences were not attributable solely to green vs blue-green taxonomic groups. The relationship between assimilation rate and growth efficiency was examined, and the possible consequences of lower values of assimilation were discussed in terms of delayed development to maturity and reproduction.

JOHNSON, M.G.(cont.)

1977 - Caloric changes along pulp and paper mill effluent plumes. J.Fish.Res.Bd.Can., 34:784-790.

Eight pulp and paper effluent plumes in Nipigon Bay were tracked with Rhodamine dye to determine dilution and nondilution losses of calories with distance and time. Dilution, as determined by Na^+ decrease, accounted for 98.5 percent of the decrease in caloric concentration along centerline trajectories of plumes over 2000 m in 7.5 h; mean caloric concentration decreased from 1583 $cal.l^{-1}$ in effluent to 50 $cal.l^{-1}$ at background stations. Nondilution caloric changes were estimated by two methods, first by examination of the main processes (respiration, settling of particles, and primary production) and, secondly, by interpretation of time series of direct measurements of caloric concentrations. By the first method, measurement of respiration indicated loss of 2.1 $cal.l^{-1}$ while particle loss from plumes was 25.5 $cal.l^{-1}$ and accrual of calories by primary production was 0.5 $cal.l^{-1}$. Integration of these results yielded an estimate of 27.1 $cal.l^{-1}$ net nondilution loss in caloric concentration along centerline trajectories over the average distance of 2000 m. By the second method, direct measurement of decrease in caloric concentration gave an estimate of nondilution loss of 45 $cal.l^{-1}$ over 2000 m. Approximately 17 percent of effluent calories were used in biodegradation and lost in sedimentation from the plume within 2000 m of the source. Environmental degradation, in terms of dissolved oxygen conditions and deposition of particles, apparently was only locally significant.

1977 - LEACH, J,H., JOHNSON, M.G., KELSO, J.R.M., HARTMANN, J., NUMANN, W., & ENTZ, B. Responses of percid fishes and their habitats to eutrophication. J.Fish.Res.Bd.Can., 34:1964-1971.

Percid fishes are found in lakes that cover a wide range of trophic conditions. The responses of percids and their habitats to progressive cultural eutrophication are predictable. Alterations in physicochemical characteristics of habitats precipitate changes in phytoplankton, macrophytes, zooplankton, and benthos that are ultimately deleterious. Enrichment can lead to favourable responses in percids, but somewhere in the continuum of trophic conditions the responses become unfavourable. The relative level at which the response becomes negative varies with the species according to tolerances to altered environment, adaptabilities to new habitat and forage base, and reproductive behaviour. Progressive eutrophication acts as a selective mechanism that leads to a predictable sequence of fish species. Other perturbations, such as exploitation and habitat modification, can act synergistically with cultural eutrophication in accelerating the sequence. As eutrophication proceeds, the succession of species may not lead to increased fish yield because part of the nutrient load may be channeled through unharvestable food chains.

1977 - KITCHELL, J.F., JOHNSON M.G., MINNS C.K., LOFTUS, K.H., GREIG, L., & OLVER, C.H. Percid habitat: the river analogy. J.Fish.Res.Bd. Can., 34:1936-1940.

JOHNSON, M.G.(cont.)

We propose that the optimum habitat of the percid fishes Perca flavescens, P. fluviatilis, Stizostedion vitreum vitreum and S.lucioperca in lakes may be defined by the littoral and sublittoral environmental conditions equivalent to those in large, temperate rivers. Analogous habitat conditions include sand or gravel substrate, low current velocity, reduced light penetration (Stizostedion spp. only), temperatures optimal for growth and reproduction, and well-oxygenated spawning substrates. The species' evolutionary origins and reproductive patterns also reflect their riverine ancestral habitat. Evidence in support of the hypothesis is derived from the diversity of papers contributed to the PERCIS Symposium.

1977 - with LEACH, J.H., MINNS, C.K., & OLVER, C.H. Limnological characteristics of Ontario lakes in relation to associations of walleye (Stizostedion vitreum vitreum), northern pike (Esox lucius), lake trout (Salvelinus namaycush), and smallmouth bass (Micropterus dolomieui). J.Fish.Res.Bd.Can., 34:1592-1601.

Commonest lake types of the 15 combinations of four fish species (walleye, northern pike, lake trout, and smallmouth bass) were walleye-pike (22 percent), pike 'only' (19 percent), lake trout 'only' (16 percent) and smallmouth bass 'only' (10 percent). Lake trout-walleye and lake trout-walleye-smallmouth bass types were extremely rare. Lake depth and area were variables of greatest significance in distinguishing lake types by discriminant analysis. Climatic factors explained the general geographic distribution of smallmouth bass. Hypotheses to explain the low frequency of walleye in small lakes include possibilities of (1) low probability of successful coexistence of pike and walleye, (2) lack of wind fetch to clear spawning areas, and (3) 'Lebensraum requirement' of the walleye.

1978 - LOFTUS, K.H., JOHNSON, M.G., & REGIER, H.A. Federal-Provincial strategic planning for Ontario fisheries: management strategy for the 1980s. J.Fish.Res.Bd.Can., 35:916-927.

A new management strategy for Ontario fisheries was addressed by a Federal-Provincial Task Force in 1974-76. It was initiated in an atmosphere of concern over the deteriorating status of fish stocks in Ontario, and indeed elsewhere in Canada. The task force published interim documents on 'Goals and Issues', on 'Mandates'. and on 'Objectives'. These received limited distribution for criticism. This report summarizes the proposed "Strategy'. Speaking generally, it has become abundantly clear that our traditional approach to fisheries management - development-orientated, exploitive, open access - is no longer appropriate in the 1970s and 1980s. That approach, together with the accelerating impacts of land and water uses that conflict with fisheries, has resulted in serious losses in our resource base, particularly during the past two or three decades. A new approach to fisheries management, characterized generally by maintenance in the north and by rehabilitation in the south is now essential. Much of the scientific and technical knowledge needed for the new approach is already available. To apply that knowledge, and to achieve the new knowledge and current data series necessary to its application, a major new initiative is necessary. That initiative, though costly in comparison to past levels of expenditure, seems easily justified in terms of the current economic value of the resources. Furthermore, additional values attributable to fisheries resources are now gaining wide acceptance; e.g., healthy fish communities are indicators of healthy aquatic environments. The new initiative will require more than just funding. It will require the evolution of different value systems, and of new and/or more explicit policies regarding:-

- a new level of public participation;
- a 'user pays' policy in place of the free access philosophy of the past - to meet some of the increased cost of managing the resource;
- more limited access and increased emphasis on protection in place of the open access, common property approach of the past;
- explicit recognition that 'experimental management' is needed to gain the new knowledge necessary to manage;
- recognition that management of fisheries requires greater attention to environmental quality matters;
- explicit allocation of those parts of the resource base available for commercial and for recreational use;
- new working arrangements between fisheries agencies and other institutions.

1979 - Temporal variation in the nutrient export of rivers draining into the Bay of Quinte, Ontario, Canada. See under MINNS, C.K.

1979 - with BERG, N. A framework for nonpoint pollution control in the Great Lakes basin. J.Soil Wat.Conserv., 34:68-72.

A description is given of the Pollution from Land Use Activities Reference Group (PLUARG), a technical advisory panel to the International Joint Commission, from its inception in 1972 to its final report in 1978.

1980 - Great Lakes environmental protection policies from a fisheries perspective. Can.J.Fish.Aquat.Sci., 37:1196-1204.

International policies in environmental protection and resources management in the Great Lakes have evolved in three fields: water quantity and quality management, fisheries management, and air pollution abatement. The general segregation of policy development ignores the complex interplay among air, water, and fisheries resources and the potential to direct wastes to selected receptors. Approaches to environmental and resources management do not deal effectively with root causes in a sufficiently broad context. Socioeconomic information is not used effectively either as yardsticks of environmental quality or as compelling arguments for remedial programs. New approaches are needed toward resources management cum environmental policy, with emphasis on participatory planning across resource sectors to optimize a diversity of long-term benefits to society. Strong political leadership is required to depolarize jurisdictional and bureaucratic empires. The

JOHNSON, M.G.(cont.)

International Joint Commission and Great Lakes Fishery Commission should collaborate to help in identification of issues and root causes, to encourage strategic planning with resource sector and public participation, and to take a broad overview of societal goals and public policy in relation to recognized finite capacity of the Great Lakes ecosystem to maintain quality of life as a long-term premise.

1980 - with COMEAU, J.C., HEIDTKE, T.M., SONZOGNI, W.C., & STAHLBAUM, B.W. Modelling effects of remedial programs to aid Great Lakes environmental management. J.Great Lakes Res., 6(1):8-21.

Computer simulation of remedial programs was carried out employing a large and diverse information base on both point and nonpoint pollutant sources in the Great Lakes basin to provide a more holistic environmental management perspective. The process utilizes a cascading system of sub-basin unit area pollutant loads (classified by land use and land form) per capita municipal pollutant inputs, river transmission factors, and remedial program effectiveness, in terms of reduced loadings to the lakes and costs. It was employed by PLUARG (Pollution from Land Use Activities Reference Group) to determine scenarios of remedial programs which apparently were practicable and would achieve target lake loads of phosphorus most cost-effectively. The analysis, presented here for Lake Erie, Lake Ontario, and southern Lake Huron, provides a means of evaluating the effectiveness of various remedial program options to fulfill commitments by Canada and the United States to load reductions for these lakes. The methodology can be extended to other pollutants as sufficient data become available to permit a suitable degree of resolution for management decisions.

1981 - And no fish swam: acid rain in Canada. Queen's Quart., 88:420-428.

1982 - Acid rain and fisheries - an overview. In; Acid Rain/Fisheries:329-339. Amer.Fish.Soc., Northeast.Div.

Nearly 60 million fishermen, almost one-quarter of Canadians and Americans, spend $18 billion annually on lodging, transportation, equipment, supplies and services. Nearly 20 million anglers spent close to $4 billion fishing for several species of trout, char and salmon in freshwaters. Presumably much of this was expended on lakes and streams threatened or damaged by airborne pollution.

Widescale expansion of the power industry during the 1950s was followed by a significant increase in mineral acids in precipitation downwind from the industrial heartland of the continent, that is, in northeastern United States and eastern Canada. In terms of H^+ loading, southeastern Canada receives 50-100 $mg.m^{-2}.y^{-1}$ and the northeastern U.S. receives 40-80.$mg.m^{-2}.y^{-1}$, compared with 5 $mg.m^{-2}.y^{-1}$ in remote continental areas. Southern Scandinavia receives 25-90 $mg.m^{-2}.y^{-1}$.

The Achilles Heel of oligotrophic lakes is lack of buffering and sensitivity to pH depression with related increase in mobility and toxicity of heavy metals and decrease in mineralization and availability of important nutrients like phosphorus and carbon. The

JOHNSON, M.G.(cont.)

threshold for most toxicological effects on a variety of fish species, pH 5.0 to 5.5, corresponds to the pH at which many natural populations of fish showed a high rate of extinction and to the pH immediately below the point of inflection of solubility of aluminum.

Damaged fisheries have been well documented in the Adirondacks of New York, brook trout lakes of Laurentides Park in Quebec, Nova Scotia salmon rivers and the Killarney, Haliburton and Muskoka lake districts of Ontario. Food chain effects are very complex but declines in productivity of many lakes could be one insidious effect of acidification; another effect is the acceleration of mercury contamination of fish. Loss of genetic stocks of fish may jeopardize rehabilitation effects.

General models of sensitivity of lakes and streams are an important part of the argument to save threatened fisheries. Investigators will strengthen existing models on an international basis, as certain well-known lakes become yardsticks of acidification damage.

Remedial programs will be staged, commencing with pollutant removal at lowest marginal cost, and will be iterative, as the understanding of effects and remedial technology continually improves to aid in fine-tuning. However, to secure the commitment to a longterm program, environmental protection policy needs to be rationalized in order to deal satisfactorily with large-scale issues. It is important that all members of the fisheries community work together to make resources planning and management a cornerstone in environmental protection, and to support such a framework with broader and stronger social and economic arguments.

1984 - Great Lakes fisheries and environmental issues. In; V.W.CAIRNS, P.V.HODSON, & J.O.NRIAGU(eds.), Contaminant Effects on Fisheries:1-7. John Wiley & Sons. ISBN 0-471-88014-0.

1985 - Acidification of Georgian Bay rivers estimated by modifications of the Wright-Henriksen model. J.Great Lakes Res., 11(2):163-170.

Data on major ions in the spring freshet of 19 rivers tributary to Georgian Bay were applied to modifications of the Wright-Henriksen model to obtain two estimates of acidification, loss in alkalinity and net SO_4^{2-} above background levels. Δ Alkalinity estimates, averaged for all rivers, were 107-147 $\mu eq.L^{-1}$ for various modifications and net SO_4^{2-} estimates averaged 108-125 $\mu eq.L^{-1}$. Both measures of acidification increased with proximity to Sudbury. The decrease in alkalinity, 45-166 $\mu eq.L^{-1}$ for the 19 rivers, was related to this spatial variability in atmospheric acid loadings, while the pH decrease, 0.2-1.6 units, reflected as well the original buffering of each river. Organic anions were important in achieving cation-anion balances, in interpretation of pH, and in modification of the Wright-Henriksen model.

1986 - Trophic structure and interactions in the Bay of Quinte, Lake Ontario, before and after point-source phosphorus control. See under MINNS, C.K.

JOHNSON, M.G.(cont.)

1986 - Phosphorus loadings and environmental quality in the Bay of Quinte, Lake Ontario. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can.Spec.Publ.Fish. Aquat.Sci., (86) :247-258.

This synthesis of Project Quinte data examines effects of magnitude and source of phosphorus (P) loadings, hydrology of the bay, and other factors on abundance and production of primary producers. Correlation and multiple regression analyses and two general deterministic models were used to interpret trends among years. Average seasonal algal biomass, chlorophyll a (Chl a) concentration, integral, and maximum volumetric rate (A_{max}) of primary production through 1972-82 were significantly correlated with point-source P loadings and percent point-source P but not with total P loading. Point-source P inputs were reduced from about 25 to 10 percent of total P loadings, and phytoplankton declined by 26-60 percent through the period. In multiple regression, P loading and flushing rate affected phytoplankton abundance and production more than water depth, radiation, and water temperature. Results from the Dillon-Rigler model, expanded to predict Chl a, transparency, macrophyte abundance, and P retention, were in good agreement with observations from 1972 to 1981. Main conclusions from application of the model to data from 1916 to 1981 were that accelerating point-source P loadings in 1956-66, aggravated by low river flows in 1962--66, led to two times the Chl a concentrations and a decline in macrophytes to one half of their former abundance, compared with 1916-55. During this early period, effects of total P loadings, often as high as in recent years, were offset by coincident changes in flushing rate, which contributed to stability in the primary producer system. During 1980 and 1981, P and Chl a concentrations declined to levels similar to those predicted in the 1930-55 period. Critical P loadings, calculated using Vollenweider's model, were close to actual river loadings during 1965-81, indicating that the bay lacked tolerance to increasing point-source P inputs. Phytoplankton abundance and production were correlated with the ratio of actual total P loading to critical P loading but not to total P loading.

1986 - with HURLEY, D.A. Overview of Project Quinte - 1972-82. In; C.K. MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can.Spec.Publ.Fish.Aquat.Sci., (86):1-6.

Background information is given on the initiation of a multi-agency research project to compare limnological features of the Bay of Quinte, Lake Ontario, before and after reduction in phosphorus inputs. Water quality trends and changes in fisheries are summarized. The experimental management approach and ecological framework for this research are discussed in general terms. A total of 23 reports on chemical and physical limnology, phytoplankton, macrophytes, zooplankton, benthos, and fish accompany this introductory report.

JOHNSON, M.G.(cont.)

1986 - with McNEIL, O.C. Changes in abundance and species composition in benthic macroinvertebrate communities of the Bay of Quinte, 1966-84. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), *Project Quinte: Point-Source Phosphorus Control and Ecosvstem Response in the Bay of Quinte, Lake Ontario*. Can.Spec.Publ.Fish.Aquat.Sci., (86):177-189.

A general decline occured in numbers and biomass of oligochaetes, sphaeriids, isopods, and, to a lesser extent, chironomids in the Bay of Quinte and adjacent Lake Ontario between 1977 and 1984. This was probably related to a decline in productivity of the bay in response to phosphorus input reductions. The amphipod *Pontoporeia hoyi* declined in the mid-1970s and recovered in the lower bay after 1977 following the collapse of a white perch (*Morone americana*) population. A coincident increase in yellow perch (*Perca flavescens*) may have suppressed numbers of the amphipod *Gammarus fasciatus*, and possibly the isopod *Caecidotea racovitzai*. Changes in chironomid associations included declines in *Chironomus anthracinus* and *C.plumosus* in the lower bay and an increase in *C.atritibia*, a species less tolerant of eutrophic conditions. Changes in oligochaete associations included declines of pollution-tolerant *Limnodrilus hoffmeisteri*, *Tubifex tubifex*, and *Quistadrilus multisetosus* throughout the bay and the increase of *Spirosperma ferox* and of *Stylodrilus heringianus*, a clean-water form found earlier only in adjacent Lake Ontario. Numbers of several species of *Aulodrilus* and *Potamothrix* usually declined. Most sphaeriid species decreased in numbers. Many species shifts were the reverse of those often observed coincident with deteriorating water quality. Species associations changed less in Lake Ontario and the lower bay toward the mouth and more so toward the middle and upper bay.

1986 - Large-scale risk assessment of acid rain impacts on fisheries: models and lessons. See under MINNS, C.K.

1986 - Nutrient loads and budgets in the Bay of Quinte, Lake Ontario, 1965-81. See under MINNS, C.K.

1986 - Effect of decreased phosphorus loading on primary production, chlorophyll *a*, and light extinction in the Bay of Quinte, 1972-1982. See under MILLARD, R.S.

1986 - Temperature and oxygen conditions and oxygen depletion in the Bay of Quinte, Lake Ontario. See under MINNS, C.K.

1986 - with CULP, L.R., & GEORGE, S.E. Temporal and spatial trends in metal loadings to sediments of the Turkey Lakes, Ontario. Can.J. Fish.Aquat.Sci., 43:754-762.

Sediment core profiles of metal concentration and ^{210}Pb activity were used to calculate metal loadings to five small Precambrian Shield lakes of the Turkey Lakes system near Sault Ste.Marie, Ontario. Background natural concentrations (pre-1900) of Al, Fe, Mn, Cu, Ni, Zn, Pb, Cd, Cr, and Hg reflected concentrations in local bedrock. Surface loading rates of Al, Cu, Ni, and Cr were not

JOHNSON, M.G.(cont.)

significantly greater than background rates. Fe and Mn enrichment of surface sediment and the downstream accumulation in the five lakes indicated the mobility of these elements. Four metals, Pb, Cd, Hg, and Zn, had significant anthropogenic inputs, which averaged 18, 1.7, 1.4, and 0.6 times background loadings, respectively. Precipitation loadings of Pb and Hg were several times greater than background accumulation in lake sediments. Precipitation loadings of Cu, Ni, Zn, and Cd were the same order of magnitude as background inputs to sediments.

KEIR, M.J.

1986 - Biological tissue archive studies. See under HYATT, W.H.

KELSO, J.R.M.

1973 - Movement of yellow perch (*Perca flavescens*), smallmouth bass (*Micropterus dolomieui*) and white bass (*Morone chrysops*) released in Long Point Bay, Lake Erie, during 1971 and 1972. Fish.Res.Bd.Can., Techn.Rept., (386).

Prior to thermal discharge at Nanticoke, marks were applied to yellow perch, 4478, smallmouth bass, 1322, and white bass, 1048, in an attempt to define normal population dispersion. Recaptures made in 1971 and 1972 did not establish any local sub-groups but indicated an onshore eastward movement (>50 percent of recoveries) in yellow perch. Smallmouth bass underwent an onshore westward movement during spring and a complementary eastward movement during late summer-early fall. White bass were far ranging, generally westward in Lake Erie, and demonstrated the most rapid rate of travel. Recapture data obtained within sixty days of release provided the most reliable information for direction and rate of travel.

Exploitation as reflected by recapture rate was greatest for yellow perch, intermediate for smallmouth bass and least for white bass. Commercial fisheries for yellow perch were selective over a narrow length range, 180 to 240 mm, while the majority of releases were 150-300 mm.

1974 - Influence of a thermal effluent on movement of brown bullhead (*Ictalurus nebulosus*) as determined by ultrasonic tracking. J.Fish.Res.Bd.Can., 31:1507-1513.

Brown bullhead (*Ictalurus nebulosus*) were captured between July 31 and August 23, 1973, both within the influence of a thermal discharge in Lake Ontario and at a control site. Ten fish were marked with ultrasonic transmitters and continuously tracked for periods of 29-344 min in the influence of the discharge. Five bullheads from the control site were similarly treated and monitored.

Fish caught and released in the discharge area remained within 50-700 m of the release point, turned frequently and sharply, and swam at an average speed of 30 cm/s. Control fish moved along shore, average speed 48 cm/s, in straighter paths up to 4200 m from the release point. On the morning following release, only 20 percent of

KELSO, J.R.M. (cont.)

fish released in the discharge were still there, indicating that association with the plume was of short duration. The study indicates that the thermal discharge can interrupt or alter normal movement patterns of brown bullhead.

1974 - with PICKETT, E.E., & DOWN, R.G. A digital echo-counting system used in determining abundance of freshwater pelagic fish in relation to depth. J.Fish.Res.Bd.Can., 31:1101-1104.

The digital echo-counting system consisted of a 200 kHz echo-sounder, cathode-ray tube, preamplifier rectifier, and digital logic. Incoming signals were gated by delayed pulses of 6.6 msec duration to represent 5 m depth shells from 5 to 25 m depth. Response to density was linear. Acoustic estimates of density ranged from 19.3/10,000 m^3 to 524.0/10,000 m^3 and trawl estimates of density ranged from 17.4/10,000 m^3 to 420.0/10,000 m^3. A high degree of correlation (0.94) existed between densities estimated acoustically and by midwater trawl. Species differences, smelt in Lake Erie, and alewife in Lake Ontario, did not seem to affect density estimates.

1975 - with MINNS, C.K. Summer distribution of the nearshore fish community near a thermal generating station as determined by acoustic census. J.Fish.Res.Bd.Can., 32:1409-1418.

The relation between thermal plumes and fish abundance and distribution was studied at the Pickering Nuclear Generating Station, Lake Ontario, using simultaneous digital echo counting and temperature monitoring systems during summer thermal stratification of the lake.

Fish relative abundance varied from 20.8/10,000 m^3 to 1,037/10,000 m^3 and both these extreme density estimates occured in the 7.5-12.5 m depth shell. Also, changes in distribution of the nearshore community were apparent during the study period, July-October. The fish community in July was pelagic and selected 10-11°C and 14-16°C. That same community later appeared to become segregated into benthic and pelagic communities. Thermal plumes, either well defined or diffuse, appeared to have little effect on the pelagic community either because fish were not available to elevated temperatures by habitat selection or because fish failed to respond to increased surface temperatures.

1976 - Movement of yellow perch (*Perca flavescens*) and white sucker (*Catostomus commersoni*) in a nearshore Great Lakes habitat subject to a thermal discharge. J.Fish.Res.Bd.Can., 33:42-53.

The thermal discharge from the Nanticoke Generating Station caused both yellow perch (*Perca flavescens*) and white sucker (*Catostomus commersoni*) to increase sharpness of turns, decrease distance between turns, and to orient into the current generated by the discharge. Conversely, fish released in thermally unaffected habitats referenced movement to the shoreline, turned less sharply, and swam greater distances between turns. The tendency for localization of movement was increased for both species when in the influence of the discharge. Swimming speeds were less for fish encountering the discharge; however, these fish had to contend with currents generated by the effluent thus making comparisons anomalous. Exposure of fish to elevated temperatures was brief and ranged from a few excursions into thermally elevated areas to approximately 9 hours. Fish transplanted from unaffected areas to the discharge area showed behaviour similar to fish caught and released at the discharge site. Two fish tracked when cooling water was discharged at ambient temperature suggested that current had a role in causing the observed changes in behaviour.

1976 - Diel movement of walleye, Stizostedion vitreum vitreum, in West Blue Lake, Manitoba, as determined by ultrasonic tracking. J.Fish.Res.Bd.Can., 33:2070-2072.

Eight walleye (Stizostedion vitreum vitreum) between 2 and 5 yr of age were equipped with ultrasonic transmitters, released, and followed for periods up to 24 h. During the study period, September 24-October 2, 1975, West Blue Lake was thermally stratified. Movement was limited to the homothermous epilimnion, above 10 m, and to the region of steeply sloping bottom of about 5-10 m which was usually within 100 m of shore. Midbasin crossings of the lake were infrequent. Transmitter attachment caused temporary high activity after which a more normal rhythm was apparent with peaks of activity at dusk and dawn. The majority, 86 percent, of observed swimming speeds were under one body length s^{-1}. Since much localized activity, too restricted to measure, was apparent, these observations must be regarded as only approximations of natural activity.

1977 - Density, distribution, and movement of Nipigon Bay fishes in relation to a pulp and paper mill effluent. J.Fish.Res.Bd.Can., 34:879-885.

Density of pelagic fish in accessible portions of Nipigon Bay was lower offshore, less than 100 fish/10,000 m^3, and greater nearshore, less than 1800 fish/10,000 m^3. Conditions at Red Rock caused intense aggregation there and caused species dominance to shift to sucker at the mill discharge from yellow perch elsewhere. Plume shape and direction did not alter the localized pattern of distribution. Two typical responses to plume concentrations were found using suckers fitted with ultrasonic transmitters. Fish released in high discharge concentrations (>15 percent dilution by volume) became disorientated for as much as several hours, then appeared to search for 'background' conditions. Fish released in low discharge concentrations (<15 percent) immediately initiated an avoidance reaction. Although individuals tended to avoid areas of altered water quality, the community aggregated at Red Rock in response to, perhaps, increased production of benthic macroinvertebrates. However, telemetry indicated that residence time was short in the area of altered water quality.

KELSO, J.R.M.(cont.)

1977 - Influence of a pulp and paper mill effluent on aspects of distribution, survival and feeding of Nipigon Bay, Lake Superior, larval fish. See under LESLIE, J.K.

1977 - Responses of percid fishes and their habitats to eutrophication. See under JOHNSON, M.G.

1977 -with BAGENAL, T.B. Percids in unperturbed ecosystems. J.Fish.Res.Bd.Can., 34:1959-1963.

A review, primarily of papers from the PERCIS symposium, indicated that growth of percids in unperturbed ecosystems, which are rare and tend to be under harsh climatic regimes, was variable, but tended to be low. Also, since growth appears to follow a clinal trend, heavily controlled by temperature, available data for unperturbed systems may not represent normal variation in growth. Recruitment did not appear to be a regular annual event and was adequately described by a wave pattern whose period was related to species longevity. Survival, therefore, was variable depending upon age-class structure of the community. Biomass, however, appeared to be a conservative property of unperturbed percid populations. Unperturbed populations should not be considered as ideal and we consider that preservation and study of unperturbed aquatic ecosystems can greatly increase understanding of the response of ecosystems to perturbation.

1977 - with WARD, F.J. Unexploited percid populations of West Blue Lake, Manitoba, and their interactions. J.Fish.Res.Bd.Can., 34:1655-1669.

West Blue Lake, Manitoba, essentially unaffected by man, sustains populations of yellow perch, Perca flavescens, and walleye, Stizostedion vitreum vitreum, which interact in two fundamental ways: perch are a major source of energy for walleye and the two species share common food organisms.

Perch adults, juveniles and fry generally contributed 80-90 percent of the energy required for the annual walleye production (340 kg) and, on the basis of conversion experiments, provided for at least 1.7 $kg.ha^{-1}$ of the observed production of 2.1 $kg.ha^{-1}$. The brief summer growth period, combined with moderate mortality, caused biomass to reach a maximum in early fall at which time production ceased.

Although walleye utilized yellow perch as its basic energy supply, behavioural differences tended to offer protection to juvenile and adult perch. Walleye were active at night, whereas older perch were inactive. Age 0 perch, during their epilimnetic phase, on the other hand, were active at night and vulnerable to walleye predation providing at least 18 percent of the observed walleye production.

Walleye and yellow perch shared the same food resources although at different times and to different degrees. This competition was most intense between walleye (>25 cm) and adult perch (>12 cm). A main food item shared was amphipods. Most other food items (sticklebacks, mayflies, crayfish) were also shared but none in equal proportions by the two percids.

KELSO, J.R.M. (cont.)

Neither of the percid species showed a preponderance of older individuals and both showed evidence of strong and weak year-classes - walleye to a greater degree. Also, for walleye at least, production was only 2.1 $kg.ha^{-1}$, and biomass appeared to be stable, approximately 900 kg. Growth for both species was less than most other percid communities and was restricted to a brief, ≈ 80 day, period.

1977 - with MINNS, C.K., & BROUZES, R.J.P. Pulp and paper mill effluent in a freshwater environment. J.Fish.Res.Bd.Can., 34:771-775.

Background and scope are provided for joint Ontario Ministry of the Environment and Department of the Environment studies of the effect of a pulp and paper mill effluent in a freshwater ecosystem. Brief descriptions of pertinent features of the pulp and paper mill and Nipigon Bay are given as related to studies presented in this volume.

1978 - Spatial distribution of nearshore fish in the vicinity of two thermal generating stations, Nanticoke and Douglas Point, on the Great Lakes. See under MINNS, C.K.

1978 - Diel rhythm in activity of walleye, Stizostedion vitreum vitreum. J.Fish Biol., 12:593-599.

Walleye, Stizostedion vitreum vitreum, generally moved along shore, mostly within 100 m, and were relatively inactive during the day. Activity, probably in relation to feeding, increased coincident with changing light intensity during the onset of darkness and daylight. Data were corroborative from ultrasonic tracking, gill net catches and echograms. Ultrasonic telemetry indicated that the majority of swimming speeds, 86 percent were below 1 $B.L.s^{-1}$ and maximum swimming speeds, up to 3.7 $B.L.s^{-1}$, coincided with periods of maximum catches by gill net shortly after dusk. Walleye were consistently in the essentially homothermous epilimnion and did not experience wide variations in ambient temperature. However, since light strongly influences activity, it is likely that light level rather than temperature limits the depth distribution of walleye.

1979 - with LESLIE, J.K. Entrainment of larval fish by the Douglas Point Generating Station, Lake Huron, in relation to seasonal succession and distribution. J.Fish.Res.Bd.Can., 36:37-41.

Larval fish were sampled by net in Lake Huron and the Douglas Point generating station throughout spring, summer, and early fall, 1975. Dominance shifted from fourhorn sculpin (Myoxocephalus quadricornis) to rainbow smelt (Osmerus mordax) then to alewife (Alosa pseudoharengus) from late April to late September. Entrainment of the major species paralleled dominance and abundance observed in the lake, but yellow perch (Perca flavescens), brook stickleback (Eucalia inconstans), and slimy sculpin (Cottus cognatus) caught in the lake - each ranging from 5 to 25 percent of the total catch - were not entrained. Conversely, white sucker (Catostomus commersoni) was entrained but not captured in the lake. Size of individuals entrained, upper limit approx. 40 mm, paralleled size of individuals

KELSO, J.R.M.(cont.)

in the lake. Vertical distribution, and thus proximity to the submerged intake, greatly influenced entrainment rate.

1979 - with MILBURN, G.S. Entrainment and impingement of fish by power plants in the Great Lakes which use the once-through cooling process. J.Great Lakes Res., 5(2) :182-194.

There are 89 thermal electric generating stations, producing 54,118 Megawatts (Mwe) of electricity, which use water directly from the Great Lakes. Electrical production per capita in Canada, 3.34 kw, is about twice that of the United States, 1.32 kw. These power plants require almost 2000 $m^{-3}s^{-1}$ of cooling water or, conservatively, >30 percent of the flow of the St.Lawrence River. Cooling water use is directly related to Mwe production and 176 L are required per kilowatt. The majority (76 percent) of power plants cause temperature increases of 12°C or less. Impingement of fish is directly related to power plant size ($\log_{10}$ number impinged = 0.414 + 1.844 $\log_{10}$ Mwe capacity) and we calculated that more than 100 x 10^6 fish will be lost at existing and proposed stations. Impingement results in direct losses to the fishery of more than 25 percent, by weight, of the annual commercial fish harvest. Entrainment is also directly related to power plant size($\log_{10}$ number entrained = 2.103 + 1.658 $\log_{10}$ Mwe capacity) and we expect more than 1.28 x 10^9 larval fish will be lost by entrainment. These estimates of entrainment and impingement are conservative since they are based upon rated pumping capacity, not actual usage which was 67 percent for the few plants that provided this information. Impingement losses, when combined with entrainment losses which will affect recruitment to some unknown degree, likely constitute a significant undesirable impact upon the Great Lakes fishery.

1979 - with MINNS, C.K. Ecological implications of the once-through cooling process of thermal electric generation in Canada. Can.Dept.Fish.Environm., Fish.Mar.Serv., MS Rept., (1482).

The use of surface waters for once-through cooling of thermal generating stations will increase. The processes in condenser cooling create impingement losses at the intake and pumps, entrainment mortality from temperature and mechanical stresses during pasage through condensers, and discharge perturbations caused by temperature and current changes. Unfortunately, the thermal effects observed at discharges have received the most attention although effects - mortality, disrupted movement patterns, loss of viable spawning and nursery areas etc. - are minimal by comparison to mortality caused by impingement and entrainment. Most of the above adverse effects from thermal power generation can be almost eliminated through intelligent siting. Disturbingly, it is now becoming apparent that fossil fuel combustion products are a far greater threat to ecosystems than thermal (or even mechanical) perturbations.

KELSO, J.R.M.(cont.)

1982 - with MINNS, C.K. Current status of lake acidification and its effect on the fishery resources of Canada. In; Acid Rain/Fisheries:69-81. Amer.Fish.Soc., Northeast.Div.

While there have been descriptions of the widespread impacts of European acid precipitation on the lakes and fisheries of Scandinavia, most studies of the Canadian situation have had a restricted geographic scope. The purpose of this study is to provide an overview of the extent of the acidification problem in Canada and to assess the current level of impact on Canadian freshwaters and their fish communities.

An appreciation of bedrock geology and existing mineral acid loading levels, is used to identify sensitive regions and place lake status in perspective with potential impacts. Recent water chemistry data from areas throughout eastern Canada are then scrutinized for evidence of acidification. The regional distribution of important fish species and communities is described and the fishery status in different areas is assessed with respect to lake acid status.

1982 - with LOVE, R.J., LIPSIT, J.H., & DERMOTT, R. Chemical and biological status of headwater lakes in the Sault Ste. Marie District, Ontario. In; F.M.D'ITRI(ed.), Acid Precipitation. Effects on Ecological Systems:165-207. Ann Arbor Sci.Publ.Inc. ISBN 0-250-40509-1.

The fish, benthos, and phytoplankton reflected to varying degrees the acidic status of their aquatic system. Although lakes in the Sault Ste.Marie District range from acidic to well buffered, the link of acidic state to atmospheric acid addition is circumstantial, as historical data is limited. Nevertheless, a significant proportion of lakes in the district are acidic, high in aluminum and lead concentrations, and poorly buffered.

Biota in these lakes are to some extent protected by their life style and species tolerance against further change in acidic status. Benthos are notably harbored against changes occuring in the water column by the ability of their microhabitat to counteract changes in lake pH. On the other hand, when behavior or development of the benthos removes them from the sediment, they are then prone to effects of predators, competitors, and lake chemistry. The phytoplankton of these lakes, while responding directly to lake conditions by shifts in community, do not appear to alter dramatically in community composition. Fish, on the other hand, operate much as the benthos with the response to acid state tempered by species tolerance, life style, metabolism of contaminants, and their compensation to changes induced by acidification in other trophic levels. In natural systems, although white sucker are generally more sensitive to low pH than brook trout, differences in life style alters exposure to and uptake of contaminants and may favor existence of white sucker. In total, it seems that although benthos and phytoplankton respond to changes in their habitat, the effect upon fish is more blatant as seen through population success or metabolism of contaminants.

KELSO, J.R.M.(cont.)

1983 - Phytoplankton production as estimated by the C^{14} technique, and populations contributing to production 1980/81/82, in the Turkey Lakes, Ontario, watershed. See under COLLINS, R.H.

1984 - with COLLINS, R.H. An attempt at assessing abundance and distribution of pink salmon (Oncorhynchus gorbuscha) prior to their entry of spawning streams. Can.MS Rept.Fish.Aquat.Sci., (1772).

Other than observations made in the spawning streams, the abundance and distribution of pink salmon (Oncorhynchus gorbuscha) in the Great Lakes is virtually unknown. In order to determine the relative abundance and habitat selection prior to spawning, we sampled the North Channel of Lake Huron using acoustic techniques, trawling and experimental gill nets. The results indicated that there was no resident population of this species in the North Channel and that their entry to the area began at the end of July when they tended to select shallow, 7 m, water and to orient to the shoreline.

1984 - with GUNN, J.M. Responses of fish communities to acidic waters in Ontario. In; G.R.HENDREY(ed.), Early Biotic Responses to Advancing Lake Acidification. Butterworth Publ., Acid Precip.Ser., (6):105-115. ISBN 0-250-40571-7.

Observed correlations between yield decreases, communities shift to tolerant species or Hg concentrations in fish flesh, and low pH, add to our understanding of acidification effects, but we have difficulty in separating pH effects from those of metal toxicity or from other stresses such as exploitation and eutrophication. Although our ability to recognize symptoms in response to acidic conditions is increasing, disruption, change and instability in fish communities are expected to occur considerably above toxic pH levels. These limitations increase the need for good case histories and experimental data to verify observations.

1984 - with KWAIN, W.H. The post-spawning movement and diel activity of rainbow trout, Salmo gairdneri, as determined by ultrasonic tracking in Batchawana Bay, Lake Superior, Ontario. Can.Field-Nat., 98(3):320-330.

Post-spawning movement of rainbow trout in Batchawana Bay of Lake Superior was examined with ultrasonic tags between 1977 and 1979. Diel activity changes dramatically from a peak between 0600 and 0900 hr to an irregular low level between 1600 and 0400 hr. Overall diel swimming speed, 1977-1979 inclusive, was 0.22 body lengths per second (BLs^{-1}). Swimming speeds measured between consecutive position fixes was largely, 73-76 percent of observations, less than 1 BLs^{-1} but swimming speeds of up to 8 BLs^{-1} occured during the dawn period of peak activity. Males re-entered the spawning stream almost three times more frequently than did females. All fish not re-entering the spawning stream oriented to the shoreline were usually within 150 m of shore and remained in shallow water (<5 m) until at least mid-June. Most fish, about 90 percent, travelled north along the shoreline. The choice of direction may have been influenced by wind-generated currents in the bay. Tracking lasted

KELSO, J.R.M.(cont.)

until 1.5 months after spawning and only two fish were lost while apparently leaving Batchawana Bay.

1984 - GRAY, J.E., & KELSO, J.R.M. An examination of historical lake and stream chemistry in north-central Ontario - can case histories document acidification? Can.Techn.Rept.Fish.Aquat.Sci., (1223).

Historical chemistry data for lakes in the Sault Ste.Marie and Blind River Ministry of Natural Resources Administrative districts of Ontario and streams draining the Canadian Shield into Lake Huron and Lake Superior were amassed regardless of source. Data were available for 117 lakes and 33 streams. No statistically significant changes occured for H^+, alkalinity, or conductivity in lakes. In streams, a significant decrease over time in alkalinity and conductivity was found for data collected in the spring. Where good cation and anion data were available, greatest decreases from expected alkalinities occured in areas of highest deposition. Constraints imposed by differing sampling and analytical methodologies hampered an overall definitive analysis of chemical change through time although a substantial data base is available. It is our conclusion that some data sets may foster construction of reliable individual lake/stream case histories but a province-wide approach using all available data would be questionable. An alternative to assessing historical rate of change in lakes or streams is to implement an appropriate continuing monitoring program.

1985 - Standing stock and production of fish in a cascading lake system on the Canadian Shield. Can.J.Fish.Aquat.Sci., 42:1315-1320.

To examine factors influencing fish biomass and production, I carried out a multiple mark and recapture program in a cascading lake system on the Canadian Shield. Standing stock and production were determined for all 'large' fish (vulnerable to the gear in use) in the system. Total fish biomass (range 5.2-24.8 $kg.ha^{-1}$) decreased with progression downstream and with increasing depth. Production ranged from approximately 2.2 to 6.6 $kg.ha^{-1}.yr^{-1}$ and operated in a manner identical to standing stock. Salmonid flesh production, however, formed a greater proportion to overall fish production in the downstream, less productive lakes. Biomass was strongly influenced by lake depth in this watershed, and this was confirmed by examination of other published data for fish biomass and production in Shield lakes.

1986 - Estimates of existing and potential impact of acidification on the freshwater fishery resources and their use in eastern Canada. See under MINNS C.K.

1986 - Large-scale risk assessment of acid rain impacts on fisheries: models and lessons. See under MINNS, C.K.

KELSO, J.R.M.(cont.)

1986 - LAM, D.C.L., BOBBA, A.G., JEFFRIES, D.S., & KELSO, J.R.M. Relationships of spatial gradients of primary production, buffering capacity, and hydrology in Turkey Lakes watershed. In; B.G.ISOM, S.D.DENNIS, & J.M.BATES (eds.), Impact of Acid Rain and Deposition on Aquatic Biological Systems, ASTM Spec.Techn.Publ., (928):42-53. ISBN 0-8031-0492-8.

The carbon uptake rate of phytoplankton was found to increase from poorly buffered, headwater lakes to better buffered, downstream lakes in the Turkey Lakes watershed near Sault Ste.Marie, Ontario, Canada. While the nutrient, sunlight, and temperature conditions remained fairly uniform, the pH, alkalinity, and dissolved inorganic carbon concentration increased in a similar manner as the primary production. Discussions are presented on the relationships of these spatial gradients and their probable causes in such a small watershed (area = 10.5 km^2). In particular, results from a hydrological model show that more groundwater flowed into downstream lakes than headwater lakes. The greater soil-water contact time and the higher concentration of calcium carbonate ($CaCO_3$) present in the till at low-lying areas cause the introduction of relatively greater quantities of Ca^{2+} and alkalinity into the downstream lakes. Thus, the development of acidification-eutrophication models must incorporate the physical, chemical, and biological processes for both soil and water.

1986 - The benthic fauna of 41 acid sensitive headwater lakes in north central Ontario. See under DERMOTT, R.M.

1986 - with MINNS, C.K., GRAY, J.E., & JONES, M.L. Acidification of surface waters in eastern Canada and its relationship to aquatic biota. Can.Spec.Publ.Fish.Aquat.Sci., (87).

Data collected by the Department of Fisheries and Oceans in lakes and rivers of eastern Canada subjected to atmospheric deposition, essentially >20 kg $SO_4^{2-}.ha^{-1}.yr^{-1}$, indicated that the trend of fewer species of fish, phytoplankton, zooplankton, and benthos below pH 6 persists. Not only are there fewer species below pH 6, but also the abundance of at least fish (as reflected by catch per unit effort) declines with decreasing pH. It is also evident that physical limits of the aquatic habitat exerts a strong influence upon diversity at all community levels. This intrinsic effect from the habitat is then further influenced by pH and alkalinity. Fish body burdens of trace metals (Hg, Al, Mn, Fe) appear weakly related to lake pH/alkalinity conditions. All provinces had fish from remote lakes with body burdens of Hg in excess of human health guidelines. In all provinces except New Brunswick, 27-47 percent of lakes had fish exceeding these public health guidelines. All indicators of lake sensitivity suggest that freshwaters, and consequently the fishery resource, of Nova Scotia are by far the most sensitive (>1200 km^2 of lake surface area already acidic, alkalinity <0 $\mu eq.L^{-1}$, approximately pH 5.3 and less). Overall, we estimate there are 700,000 lakes in eastern Canada receiving deposition considerably above background; that 4,243 km^2 (>14,000 lakes) are currently acidic; and that more than 150,000 lakes have a pH <6.0, a level identified as a threshold of effect.

KELSO, J.R.M.(cont.)

1986 - with MINNS, C.K., LIPSIT, J.H., & JEFFRIES, D.S. Headwater lake chemistry during the spring freshet in north-central Ontario. Wat.Air Soil Pollut., 29:245-259.

From data on 30 headwater lakes in north-central Ontario we found that, during the spring snowmelt of 1981, all lakes underwent serious declines in alkalinity. Generally, SO_4^{2-}, alkalinity, Ca^{2+} and Mg^{2+} concentrations were reduced by runoff and rain then recovered to intermediate levels after the major inputs declined. As expected, a range in responses was evident with lower alkalinity systems showing the greatest changes. The observed changes, however, were consistent with acid loading having depleted alkalinity.

In calculating an input-output budget for each lake, we found that changes in Cl^-, Na^+, and K^+ were consistent with atmospheric inputs being the major source as the difference between the expected input and the actual contribution from rain and snow had a mean near zero. There appears to be a significant ≈45 percent, watershed source of sulphate that we hypothesize is from dry deposition occuring prior to snowfall and is eluted with the melting process. With refinements to a mass balance approach explaining the watershed source of SO_4^{2-} and Al, we feel it is possible to predict springtime lake changes given a few chemical and simple morphometric variables.

KWIATKOWSKI, R.E.

1977 - with EL-SHAARAWI, A.H. Physico-chemical surveillance data obtained for Lake Ontario, 1974 and their relationship to chlorophyll a. J.Great Lakes Res., 3(1-2):132-143.

A variety of chemical and physical parameters were measured on 15 cruises conducted on Lake Ontario from April to November, 1974. Analyses of chlorophyll a, including pheopigments, indicated that chlorophyll concentrations followed a biomodal seasonal pattern. Significant correlations were found between chlorophyll a and the other parameters measured. First order autoregressive equations were established for all measured parameters. Multiple regression analyses indicated that 74 percent of the spring, 49 percent of the summer and 78 percent of the fall variability in chlorophyll a concentration could be explained with the physico-chemical parameters measured in the present study.

1977 - EL-SHAARAWI, A.H., & KWIATKOWSKI, R.E. A model to describe the inherent spatial and temporal variability of parameters in Lake Ontario 1974. J.Great Lakes Res., 3(3-4):177-183.

A statistical model was developed to evaluate the temporal and spatial variability inherent in limnological sampling of large lakes. The model was applied to Secchi disc, transmissometer readings, temperature, integrated total particulate carbon, integrated total particulate nitrogen, and integrated chlorophyll a. The data were obtained during the 15 Lake Ontario surveillance cruises conducted between April - December, 1974. Based on the

KWIATKOWSKI, R.E.(cont.)

model, Lake Ontario was classified into a set of seven statistical zones for each parameter. An estimate of the seasonal cycle for each parameter was also obtained. It was found that the seasonal variability was more pronounced than the spatial variability for all parameters analyzed. However, a significant horizontal variability did exist, and this variability must be recognized in future modelling efforts.

1978 - Scenario for an ongoing chlorophyll a surveillance plan on Lake Ontario for non-intensive sampling years. J.Great Lakes Res., 4(1):19-26.

The present study proposes an effective non-intensive sampling program for chlorophyll a on Lake Ontario. Three years of chlorophyll data were used to establish three statistically homogeneous zones, significantly different at the 5 percent level. These zones are referred to as offshore, inshore and point source areas. The seasonal cycle for each zone is presented as is the number of samples needed to estimate the mean of each zone within 1 percent, 5 percent and 10 percent of the true mean, with a 95 percent confidence level.

1980 - MacKINNON, M., & KWIATKOWSKI, R.E. A survey of ATP concentrations in Lake Ontario, 1975-1976. J.Great Lakes Res., 6(3):177-183.

The total microbial biomass concentrations of Lake Ontario were estimated with the adenosine-5'-triphosphate (ATP) technique for a winter, spring and summer period in 1975-76. The average total column ATP value for December and April was found to be 0.1 $mg.m^{-3}$ while in August the average value was 0.269 $mg.m^{-3}$. In winter and spring the ATP concentrated nearshore and no vertical gradients in ATP concentration existed. In summer the major portion of the micro-organism biomass existed in the upper 20 metres and the south shore was richer than the north shore.

1980 - A new approach to the philosophy of chlorophyll a surveillance. Can.Techn.Rept.Fish.Aquat.Sci., (976):152. (Abstract).

In an attempt to indicate areas of non-compliance with specific water quality objectives, and to provide water quality trend information, the International Joint Commission has adopted a policy of conducting large lake synoptic cruises on Lake Ontario on an annual basis. Information indicating that the temporal variability for chlorophyll a is 3 to 15 times greater than the spatial variability in Lake Ontario, has led to a time series study. Chlorophyll a samples were obtained weekly from mid-March to mid-November at five nearshore stations in Lake Ontario. A model relating the chlorophyll a concentration at 1, 5, and 10 m to light intensity and water temperature is presented. The importance of properly defining the seasonal cycle with respect to trend analysis is discussed.

KWIATKOWSKI, R.E.(cont.)

1980 - Regionalization of the Upper Great Lakes with respect to surveillance eutrophication data. J.Great Lakes Res., 6(1):38-46.

Data on six eutrophication parameters routinely measured on surveillance cruises were used to statistically (P ≥0.10) regionalize the Upper Great Lakes, using a zonation technique. Inputs and currents played an important role in defining the aeral extent of the regions produced. Regionalization of North Channel-Georgian Bay and Lake Huron compared favourably to that developed by the International Joint Commission, whereas differences in the number of zones used to characterize Lake Superior resulted.

1980 - The use of the Shannon-Wiener diversity index to delineate the horizontal distribution of crustacean zooplankton communities in Lake Superior, 1973. Hydrobiologia, 68(3):247-256.

The Shannon-Wiener diversity index was calculated for the total zooplankton community found in Lake Superior in 1973, as well as for its components (i.e., Calanoida, Cyclopoida, Cladocera and nauplii). These values were then subjected to a model to develop statistically homogeneous zones, and to determine the temporal and spatial variability of the diversity values. A region roughly following the 100 meter depth profile and having an average yearly temperature of 9.8°C was found to exist along the south and southwestern shores of Lake Superior. In this region significantly (P ≥0.10) higher diversity indices were found.

1980 - Chlorophyll a measurements from Lake Ontario, 1974-79. Can.Techn.Rept.Fish.Aquat.Sci., (933).

In 1974 a surveillance sampling programme was designed for Lake Ontario. Permanent stations were established to give an overview of the lake, with maximum sampling occuring in the 2 to 10 kilometer range from shore (the area which showed the maximum variability in the past). Though cruise frequency varied between 1974 and 1979, station locations remained constant. The following report gives the chlorophyll a isopleths obtained from the 64 cruises conducted on Lake Ontario, between 1974 and 1979.

LESLIE, J.K.

1973 - with DEVEY, L., MUNAWAR, M., NAUWERCK, A., & PICKETT, E. A comparison of electronic particle counters and inverted microscope methods for counting phytoplankton. Fish.Res.Bd.Can., Techn.Rept., (394).

The Coulter Counter Model B and the Millipore πMC Particle Measurement Computer System were compared with the inverted microscope technique in counting and sizing Lake Ontario phytoplankton samples. Little correlation existed between electronic and microscopic counts. Evidence strongly suggested that until better sample preparation techniques were devised, these instruments are suitable for pure culture counting and specific investigations such as total volume or areal measurements, dimensional features,

LESLIE, J.K. (cont.)

e.g. longest projected length, cell width, mean volume of a species, etc., but not for gross studies of natural phytoplankton populations.

1977 - with KELSO, J.R.M. Influence of a pulp and paper mill effluent on aspects of distribution, survival and feeding of Nipigon Bay, Lake Superior, larval fish. Bull.Environm.Contam.Toxicol., 18(5):602-610.

Surface distribution of Nipigon Bay larval fish was characterized by high abundance, between 500 and 2100 larval fish/10,000 m^3 near shore, particularly in proximity to the pulp and paper mill effluent discharge, and low abundance, less than 100/10,000 m^3 away from shore. Static bioassay indicated that approximately 60 percent effluent concentration was intolerable to the natural mixed larval fish community. No wood fibre was found among stomach contents and no difference was apparent in stomach contents of fish caught in influenced and uninfluenced areas. Data therefore suggest that larval fish either were not greatly influenced by plume conditions or were transients.

1977 - Characterization of suspended particles in some pulp and paper mill effluent plumes. J.Fish.Res.Bd.Can., 34:791-797.

Some physical characteristics of the suspended particles from seven pulp mill effluent plumes were analyzed electronically. An effluent flow rate of 1.2 $m^3.s^{-1}$ contained a mean of 75.9 x 10^9 $\mu m^3.1^{-1}$ particle volume in a size range of 3.2-84.0 µm 'diameter'. The visible particle surface area was 334.8 $cm^2.1^{-1}$ and there were 1045 x 10^3 $particles.ml^{-1}$. A slight increase in size was detected as the particles aged in the plume. The transported particulates were reduced by dispersion and sedimentation to approximately 5 percent by a transit of less than one km, but effluent was still detectable two km from the point source.

1978 - Electronic and Utermöhl comparative techniques in quantitative analysis of freshwater particulates. Hydrobiologia, 57(3):225-239.

The Coulter Counter Model B and the Millipore Particle Measurement Computer System were compared with the Utermöhl technique in counting and sizing test objects and suspended freshwater particulate matter. Replicate samples of lake water and pulp mill effluent were analyzed with the electronic instruments for an estimate of counting error ($SE.t.100/\bar{x}$). Coulter Counter error for determination of number, volume, and diameter of homogeneous particles was less than 10 percent, and for natural populations of freshwater particles, less than 20 percent. Millipore errors of number, area, and horizontal chord were roughly twice these values. Precision was least at low concentration of particles. In practical applications, pulp mill effluent analyses were characterized by close correlation between electronic methods of counting, but lake water particle determinations failed to relate. Microscopic counts and sizes of freshwater particles were generally unrelated to electronic measurements. A definite electronic instrument

LESLIE, J.K. (cont.)

specificity for homogeneous particles was apparent. Wide variations in determinations of characteristics by electronic and manual methods existed. The greatest problem in the estimation of freshwater biomass is the determination of the unknown detrital fraction.

1979 - with KOZOPAS, R., & HYATT, W.H. Considerations of entrainment of larval fish by a St.Clair River, Ontario, power plant. Can.Dept.Fish.Environm., Fish.Mar.Serv., Techn.Rept., (868).

Larval fish entrainment by the Lambton generating station, St.Clair River, Ontario, was estimated at 22.5 x 10^6 for the ten week sampling period (April 10 - June 21, 1978). Smelt (Osmerus mordax) comprised approximately 90 percent of the total. Two larval species previously unreported in the river, fourhorn sculpin (Myoxocephalus quadricornis) and silver chub (Hybopsis storeriana) together formed 3 percent, while seven species formed the remaining 1 percent. The total absence of walleye (Stizostedion vitreum vitreum) larvae in all samples generated increased concern for its abundance, if not survival, in the area.

1979 - Entrainment of larval fish by the Douglas Point Generating Station, Lake Huron, in relation to seasonal succession and distribution. See under KELSO, J.R.M.

1979 - KOZOPAS, R., & LESLIE, J.K. Larval fish entrainment at Lambton TGS - 1978. Ontario Hydro, Environm.Protect.Dept., CTS-07015-8.

For the total volume of cooling water drawn in during sampling, an estimated 3.21 x 10^6 larval fish were entrained. Of this total, smelt larvae comprised 93.6 percent, sculpin 0.3 percent, silver chub 0.6 percent, and miscellaneous 5.5 percent. Total entrainment for the entire sampling period was estimated at 22.5 x 10^6 larval fish.

No larval walleye were caught in the station intake forebay.

1980 - with LESLIE, R.V. A versatile, low-cost current meter for the hydrobiologist. Can.Techn.Rept.Fish.Aquat.Sci., (926).

A small but rugged, versatile current meter that was designed primarily as a peripheral tool in the small-craft sampling of plankton and larval fish is described. Only a single moving part, the rotor, is mechanically involved, and 'on site' velocity and temperature information are obtained directly from the calibrated meter, or indirectly from chart and tape records. The current meter may be rigidly secured to plankton samplers, moored for in situ collection, or simply hand-held for mobile operation. The instrument may find wide application with hydrobiologists and hydrologists.

1980 - with MOORE, J.E. Measurement of particulates entrained in some Great Lakes power plant cooling water: an exercise in futility. Environm.Pollut., Ser.A, 22:179-185.

LESLIE, J.K. (cont.)

An investigation into the physical effects of entrainment on suspended particles in condenser cooling water at three Great Lakes electric power generating stations was attempted, using mostly electronic particle sensing methods. Particles in the waste heat effluent analyzed with a Coulter Counter indicated an increase in total number and volume by 11 percent and 5 percent respectively and a decrease in mean size of 3 percent ($p < 0.01$) relative to particles in intake cooling water. These changes were most evident in the smallest sized particles. Image analysis of some of the particles detected a significant ($p < 0.05$) 18 percent increase in the number of discharge particles.

Although mean particle surface area, size and phytoplankton biomass were reduced, while phytoplankton numbers were higher in discharge samples, these differences were not statistically significant.

Based on actual differences in counts of companion intake and discharge samples, a ±5 percent change in particle number would necessitate 2839 samples for the Coulter Counter, 1541 for the image analyser and 7021 for the inverted microscope counting technique.

The detection with certainty of small changes in some physical characteristics of suspended particles was frustrated by problems with analyses and an impotent sampling programme.

1983 - Cooling water flow velocity in relation to collection of entrained larval fish at power plants. Can.J.Fish.Aquat.Sci., 40:370-373.

Velocity of condenser cooling water at numerous sampling sites at some Great Lakes power plants was examined in relation to larval fish entrainment. Current velocity was found to differ significantly in many cases at all depths, for sampling locations spaced 1 m apart in the vertical plane. Extensive use of current meters showed that a simple, presampling study of current velocity at the intake or discharge could improve the accuracy of entrainment estimates.

1983 - LUM, K.R., & LESLIE, J.K. Dissolved and particulate metal chemistry of the central and eastern basins of Lake Erie. Sci.Total Environm., 30:99-109.

Dissolved and particulate forms of Al, Cd, Co, Cu, Fe, Mn, Ni, Pb and Zn were determined in the central and eastern basins of Lake Erie during May, August and September 1978.

No temporal or spatial differences in the average concentrations of dissolved Cu, Ni, Al and Fe were observed between May and September. In contrast, Mn and Zn showed significant seasonal variations with Mn having distinct concentration maxima in both basins during September. This behaviour is attributed to net release of Mn and Zn from the bottom sediments.

Phytoplankton activity is shown to be important in causing large increases (1.8 - 5.4 times the concentrations in May) in particulate elemental concentrations during the bloom periods. The removal of Cu, Ni, Pb and Zn from the water column is mediated by the decay of plankton populations.

LESLIE, J.K. (cont.)

1983 - with MOORE, J.E., HYATT, W.H., & TIMMINS, C.A. Seine for sampling larval fish in shallow water. Progr.Fish-Cult., 45(2):130-131.

During the first 5 weeks of spring, 43,000 larval fish from 15 species were obtained with the seine in an area of the Bay of Quinte, Lake Ontario, whereas 17,000 larvae from 6 species were caught in open-water tows with paired, 0.5-m nets. The total volume of water filtered by the two types of samplers was about the same. After a complete field season, involving more than 200 hauls over a variety of substrates, workers concluded that sampling with the seine was not physically difficult. Usefulness of the equipment, particularly in adverse weather and substrates, is limited largely by the experience and diligence of the users.

1984 - with GORRIE, J.F. Early development of the muskellunge, Esox masquinongy, of Stony Lake, Ontario. Can.Techn.Rept.Fish.Aquat. Sci., (1319).

Development of muskellunge, Esox masquinongy, reared at the Deer Lake Hatchery (Ontario Ministry of Natural Resources) in 1981 and 1982, was studied. Fertilized eggs (preserved mean diameter = 2.9 mm) of muskellunge hatched after 193 degree-days (in 1981), and newly hatched larvae ranged from 7.8 to 8.9 mm total length (TL), mean = 8.6 mm. The head was deflected over a large, amber yolk sac. Pectoral buds were present. Eyes were lightly pigmented; a band of melanophores extended hypaxially from the head to the caudal region. At 14 to 15 mm TL, larvae were elongate of body and snout, had teeth, and 66 myomeres. First exogenous feeding occured at about 14.5 mm, when the swim bladder inflated. The full complement of fin rays occured in 29.1 mm larvae and the fin fold disappeared at 41 mm TL. First squamation appeared at 53 mm TL. Early juveniles were pigmented laterally with indistinct vertical bars and vermiculations; the lateral line, dorsal mid-line, and venter were essentially unpigmented.

1985 - with GORRIE, J.F. Distinguishing features for separating protolarvae of three species of esocids. Can.Techn.Rept.Fish. Aquat.Sci., (1359):1-19.

Cursory examination of the pigmentation, oil globule size and distribution, and preanal myomere count will assure separation of grass pickerel from northern pike and muskellunge. However, the relative similarity of northern pike and muskellunge in myomere count and preanal length at most comparative sizes necessitates closer scrutiny of these species. If differences are not evident in head, eye, and yolk sac pigmentation, and the size and form of oil globules, separation should result from several additional comparisons. In northern pike, head length and snout to ventral fin fold length, relative to total length, are greater, and the yolk sac smaller, than in muskellunge. A number of criteria for distinguishing between protolarvae of grass pickerel, northern pike, and muskellunge, are given.

LESLIE, J.K.(cont.)

1985 - with MOORE, J.E. Ecology of young-of-the-year fish in Muscote Bay (Bay of Quinte), Ontario. Can.Techn.Rept.Fish.Aquat.Sci., (1377).

Young-of-the-year fish and zooplankton were routinely collected from April to September, 1981, in Muscote Bay, Bay of Quinte. Larval fish were most abundant during mid-late May and early June; zooplankton peaked in early June and July. There were 26 taxa of fish, of which yellow perch, Perca flavescens, white sucker, Catostomus commersoni, gizzard shad, Dorosoma cepedianum, and alewife, Alosa pseudoharengus, were dominant species. Highest species diversity was in early to mid-June; lowest diversity occured in early May and August. Abundance and diversity of virtually all species inshore exceeded those in open waters. Cladocerans, led by Bosmina longirostris, formed 43 to 86 percent of all zooplankton, which was notably diverse and abundant, but differentially distributed. Food for young fish was apparently sufficient, but selection and avoidance of certain food items was evident. Certain species were emigrants, others were immigrants. In general, Muscote Bay served as a spawning location, a nursery, and as a residence for most young fish.

1986 - Nearshore contagion and sampling of freshwater larval fish. J.Plankton Res., 8(6):1137-1147.

The existence of larval fish contagion and its approximate magnitude in four different biotopes at the shore of a river, surface and at fixed depth at an exposed coast of a large lake, and in a shallow, sheltered bay, was investigated, using passive and active sampling. Non-random distributions were the rule; patchiness differed according to species, size, abundance and diurnal movement, and was inversely related to distance from shore. Characterization of contagion was hindered by sampling equipment and techniques, which were found wanting.

1986 - with MOORE, J.E. Changes in lengths of fixed and preserved young freshwater fish. Can.J.Fish.Aquat.Sci., 43:1079-1081.

The lengths of body parts of several species of young freshwater fish were measured to determine short- and medium-term effects of fixation and preservation. Shrinkage (up to 4.9 percent) was the rule, but lengths also increased, or remained static; rigor mortis was probably the main cause of immediate change. However, measurement error probably affected precision in the smallest lengths. Body parts changed differentially; these changes were not species specific, nor was the type of fixative or preservative significant. Trunk and snout to vent length indicated most susceptibility to change (especially shrinkage); head length was least affected. Changes were considered of little or no practical consequence for taxonomy and growth studies.

LESLIE, J.K. (cont.)

1986 - with METCALFE, J.L., & RALPH, K.M. Early development of the common shiner, Notropis cornutus (Mitchill), in southern Ontario. Can. Techn.Rept.Fish.Aquat.Sci., (1455).

Early development of the common shiner, Notropis cornutus (Mitchill), obtained from southern Ontario in 1981 to 1983 and 1985, is described and illustrated. Mean diameter of preserved, fertilized eggs ranged from 1.3 mm in 1982 to 1.6 mm in 1983; hatching ranged from two days at 18.2°C to six days at 12.9°C. Newly-hatched larvae (3.0 to 4.6 mm) had a large bulbous yolk sac, incomplete mouth, pectoral fin buds, a straight urostyle, and were unpigmented. Larvae retained yolk until about 8 mm, developed all fins (at least rudimentary) by 11 mm, had 26 preanal and 13 postanal myomeres, and were characteristically pigmented with two serial rows on the dorsum, a faint lateral stripe, a ventral arrow-shaped pattern on the gut, a supra-anal spot, and an hypural patch. Prepelvic and predorsal lengths of juveniles were equal. They first developed scales at about 22 mm, and had 37 to 40 vertebrae.

LIPSIT, J.H.

1982 - Chemical and biological status of headwater lakes in the Sault Ste.Marie District, Ontario. See under KELSO, J.R.M.

1983 - Phytoplankton production as estimated by the C^{14} technique, and populations contributing to production 1980/81/82, in the Turkey Lakes, Ontario, watershed. See under COLLINS, R.H.

1986 - Headwater lake chemistry during the spring freshet in north-central Ontario. See under KELSO, J.R.M.

LOVERIDGE, C.C.

1975 - with COOK, D.G. A preliminary report on the benthic macroinvertebrates of Georgian Bay and North Channel. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (610).

In September 1973, benthos samples were taken in Georgian Bay and North Channel using a uniform grid pattern of 121 and 55 stations respectively. In 111 Georgian Bay stations that contained benthos, we found a mean of 3303 macroinvertebrates/m^2 composed of 51 percent Pontoporeia affinis 12 percent Oligochaeta, 20 percent Nematoda, 13 percent Sphaeriidae, and 3 percent Chironomidae. The mean biomass was 0.367 g/m^2 to which P.affinis contributed 69 percent, Oligochaeta 14 percent, Nematoda 3 percent, Sphaeriidae 9 percent, and Chironomidae 1 percent. In 53 North Channel stations containing benthos we estimated a mean total of 4636 macroinvertebrates/m^2 consisting of 48 percent P.affinis, 11 percent Oligochaeta, 15 percent Nematoda, 18 percent Sphaeriidae, and 4 percent Chironomidae. Mean biomass was 0.542 g/m^2 to which P.affinis contributed 70 percent, Oligochaeta 11 percent, Nematoda 1 percent, Sphaeriidae 10 percent, Chironomidae 2 percent, and miscellaneous taxa 6 percent.

LOVERIDGE, C.C.(cont.)

Major trends in the two bodies of water are as follows:- 1. in both Georgian Bay and North Channel, benthic populations increased towards the north and north-west shores: 2. the abundance of most macroinvertebrates increased as depth decreased: and 3. abundance tended to be greater in sediments with relatively large particle sizes than in fine-grained sediments.

LUXON, P.L.

1975 - Methylation of lead in the environment. See under WONG, P.T.S.

1975 - Methylation of lead and selenium in the environment. See under WONG, P.T.S.

1976 - Methylation of selenium in the aquatic environment. See under WONG. P.T.S.

1977 - Methylation of arsenic in the aquatic environment. See under WONG, P.T.S.

1977 - Methylation of selenium in the aquatic environment. See under WONG, P.T.S

1978 - Toxicity of a mixture of metals on freshwater algae. See under WONG, P.T.S.

1979 - Microbial methylation of lead compounds in the aquatic environment. See under WONG, P.T.S.

MILLARD, E.S.

1978 - Experimental ecosystems as a means of evaluating the fate and effect of contaminants in aquatic ecosystems. See under HODSON, P.V.

1986 - Seasonal trends in turnover times of orthophosphate in the Bay of Quinte, Lake Ontario. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can. Spec.Publ.Fish.Aquat.Sci., (86):91-99.

Orthophosphate turnover times were measured weekly throughout the Bay of Quinte, Lake Ontario, from May through September. The longest turnover times were in May but decreased to 5 min at some stations by early July. At this time, uptake was dominated by bacteria-size particles (0.45-1 µm) in the middle and lower bay as well as nannoplankton (1-8 µm) in the upper bay. Several factors suggested that the seston was phosphorus starved at this time. Total phosphorus, chlorophyll a, turnover times, and phosphorus uptake by larger particles (>8 µm) increased by August, indicating that phosphorus supply had increased. Turnover times were fastest in the middle and lower bay when thermal stratification occured. The shallow, fully mixed upper bay stations that were close to high point-source phosphorus loadings had long turnover times most frequently. The highest frequency of rapid turnover times occured in

MILLARD, E.S.(cont.)

the middle bay where the distance from point-sources of phosphorus and strong thermal stratification lowered available phosphorus supply.

1986 - Effect of light climate, photosynthetic capacity, and respiration on gross integral primary production and net primary production potential in the Bay of Quinte, Lake Ontario. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can.Spec.Publ.Fish.Aquat.Sci., (86):128-138.

Primary production, chlorophyll a (Chl a), light extinction, mixing depths, and community respiration were measured throughout the Bay of Quinte, Lake Ontario, from 1973 to 1982. Model estimates of hourly integral primary production (ΣA) agreed closely with measured values using a shipboard incubator. Most of the variance (82.8 percent) was explained by Pmax,Chl. a/ϵ_{PAR}, the ratio of standing crop times its collective photosynthetic capacity over the extinction coefficient for photosynthetically available radiation. Chl a had an important effect on light penetration throughout the bay. Nonalgal sources of light extinction ($_{w}$) were high in the upper bay (0.92.m^{-1}) but declined in the lower bay (0.43.m^{-1}). High values for ϵ_w and ϵ_s, the self-shading coefficient (0.023 ln units.mg Chl $a^{-1}.m^{-2}$), reduced the euphotic zone content of Chl a (ΣB) compared with other lakes. This negative effect on ΣA was offset by high values for P_{max}(3-7 mgC.mgChl $a^{-1}.h^{-1}$). Prior to phosphorus control, values for ΣB and Chl a reached theoretical maxima in the upper bay. The underwater light climate had become limiting to further increases in standing crop due to high light extinction caused by high phosphorus loading. In contrast, the seasonal trend in vertical mixing depths controlled the potential for net primary production in the lower bay.

1986 - with JOHNSON, M.G. Effect of decreased phosphorus loading on primary production, chlorophyll a, and light extinction in the Bay of Quinte, Lake Ontario, 1972-82. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control. and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can.Spec.Publ.Fish.Aquat.Sci., (86):100-113.

A study was carried out in the Bay of Quinte, Lake Ontario, from 1972 to 1982 to determine the effectiveness of phosphorus (P) controls (1978-82) at lowering chlorophyll a (Chl a) concentrations, primary production rates (A_{max}) and light extinction (ϵ_{PAR}). Prior to P controls, conditions in the upper bay placed it amongst some of the most eutrophic temperate-climate lakes in the world. Rapid increases to high peak values in Chl a (60-100 mg.m^{-3}), A_{max}(400-500 mg C.$m^{-3}.h^{-1}$), and ϵ_{PAR} (2.75-3.75.m^{-1}) occured each summer prior to P control. Following P controls, summer means and maxima for these parameters have declined substantially. Total gross primary production (May-September) has declined 37-46 percent in the upper bay and 26-28 percent in the middle and lower bay. The gradient from upper to lower bay in parameters such as Chl a, A_{max}, and ϵ_{PAR}, directly influenced by algal density, was

MILLARD, E.S.(cont.)

less pronounced after P control. Self-shading properties of the phytoplankton community reduced the differences between regions of the bay in integral primary production (ΣA, mg $C.m^{-2}.h^{-1}$) but this was even more evident with P control. River flow and point-source P loadings explained much of the variance in P concentrations and thus productivity in the upper bay.

1986 - Trophic structure and interactions in the Bay of Quinte, before and after point-source phosphorus control. See under MINNS, C.K.

MINNS, C.K.

1975 - Summer distribution of the nearshore fish community near a thermal generating station as determined by acoustic census. See under KELSO, J.R.M.

1976 - LAM, D.C.L., MINNS, C.K., HODSON, P.V., SIMONS, T.J., & WONG, P. Computer model for toxicant spills in Lake Ontario. In; J.O.NRIAGU(ed.), Environmental Biogeochemistry. Volume 2. Metals Transfer and Ecological Mass Balances:743-761. Ann Arbor Sci.Publ.Inc.

In essence, the results of the model show that the advective and diffusive transports are very effective mechanisms in the dispersion of the spilled substances both horizontally and vertically in large water basins, particularly in stormy conditions. Moreover, for certain substances such as lead nitrate, the most dominant factor is the chemical interaction between the substances and the water quality parameters in the neighbourhood of the spill. The model results indicate that the combination of these physical and chemical processes may produce harmful effects on aquatic life over a large area in a couple of days. Obviously, there are technical difficulties, especially in stormy conditions, in carrying out remedial measures for such a vast volume of water. It appears, therefore, that preventative measures should be considered more seriously as the necessary procedures for controlling the accidental discharge of toxic materials into large water basins.

To provide some guidelines for establishing the preventative measures, the present model can be used for a number of cases of toxicant spills for different natural conditions and backgrounds. The results can then be combined with a ranking list of these toxicants which is based on other aspects such as the frequency of transportation. The final listing will therefore be more complete and comprehensive. However, the extent to which the model can predict depends very much on the current research efforts in the various fields of geochemistry, chemistry, biology, physics and mathematics as pointed out during the discussion.

The model has been a first attempt at combining recent techniques in computer modeling and knowledge in various disciplines of science for simulating toxicant spills. It is by no means the ultimate model. Hopefully, it will spark further cooperation between modelers and experimentalists to attain more accurate predictions for water management purposes, especially in coastal zones of the Great Lakes Basin.

MINNS, C.K.(cont.)

1977 - Limnological characteristics of Ontario lakes in relation to associations of walleye (Stizostedion vitreum vitreum), northern pike (Esox lucius), lake trout (Salvelinus namaycush), and smallmouth bass (Micropterus dolomieui). See under JOHNSON, M.G.

1977 - Pulp and paper mill effluenct in a freshwater environment. See under KELSO, J.R.M.

1977 - Percid habitat: the river analogy. See under JOHNSON, M.G.

1977 - Analysis of a pulp and paper mill effluent plume. J.Fish. Res.Bd.Can., 34:776-783.

Several chemical surveys of a pulp and paper mill effluent plume in Nipigon Bay, Lake Superior, are analyzed to determine the average area and volume contained by a range of isoconcentration boundaries. Sodium, dissolved organic carbon, particulate organic carbon, and particulate organic nitrogen are the chemical variables used to examine changes occuring in the plume. Data are analyzed from three sampling regimes: (1) dye-slug tracking which allows interpretation of time-related processes, (2) surface surveys which indicate the areal extent of the plume, and (3) vertical profile surveys which indicate the degree of depth penetration for effluent components.

Dilution dominates in the plume, though the nonconservative substances undergo significant changes. The plume area enclosed in a contour of 1 percent effluent is approximately 1.5 km^2. Mass balance calculations indicate exchanges occuring between the plume and the old fiber beds in the vicinity of the effluent outfall.

1978 - Prediction of egg development times of freshwater copepods. See under COOLEY, J.M.

1978 - with KELSO, J.R.M., & HYATT, W. Spatial distribution of nearshore fish in the vicinity of two thermal generating stations, Nanticoke and Douglas Point, on the Great Lakes. J.Fish.Res.Bd.Can., 35:885-892.

At Nanticoke, Lake Erie, 1974, mean fish density varied considerably, range 162-14,204/10,000 m^3, as estimated by digital acoustic fish enumeration. At Douglas Point, Lake Huron, 1975, mean density varied less, range 108-671/10,000 m^3. At both sites fish densities were generally greatest in the shallowest, 3-5 m, depths. At Nanticoke, where the nearshore has low relief, there were no distinguishable communities. At Douglas Point, where depth increases rapidly offshore, there was evidence of benthic and pelagic communities. There was no evidence of altered fish distribution in relation to temperature. At Nanticoke, there was no vertical variation in temperature and no vertical response was to be expected. At Douglas Point there was thermal stratification present in the summer and there was no apparent response. The influence of incident radiation was uncertain because of the effects of diurnal migrations. At both locations fish were clustered horizontally to varying degrees in the spring and fall, while in the summer fish were distributed more evenly. Densest clusters were usually in the vicinity of the turbulent discharge at both locations. The lack of temperature response and the similarity of Nanticoke with situations at nearby streams on Lake Erie, suggest that the fish are responding to currents and perhaps topography.

1979 - Biological implications of the once-through cooling process of thermal electric generation in Canada. See under KELSO, J.R.M

1979 - with JOHNSON, M.G. Temporal variation in the nutrient export of rivers draining into the Bay of Quinte, Ontario, Canada. Wat. Resourc.Bull., 15(4):1061-1072.

Annual exports of total phosphorus, soluble reactive phosphorus, and total nitrogen are presented for the period 1965-1974, for five rivers draining into the Bay of Quinte, Lake Ontario.

The export values are typical for the physiography and land use though the results indicate that soluble reactive phosphorus exports for the four largest rivers have been declining. Also the variation in export of total phosphorus and total nitrogen is highly correlated with variation in annual runoff. This is noted as being a factor deserving more attention in future efforts to classify nutrient export values in relation to land use and geology.

1981 - Acid rain: a preliminary estimate of the risk to Ontario's inland fisheries. Can.MS Rept.Fish.Aquat.Sci., (1622).

The lake inventory database of the Ontario Ministry of Natural Resources, in conjunction with counts of numbers and areas of lakes by watershed and size, are used to estimate the quantity of Ontario's inland fishery resources which are at risk from acid precipitation. The inventory data include conductivity, pH, morphometry and fish community information. These data are taken to be representative of the total, after correction for the over representation of brook trout, Salvelinus fontinalis. Lakes are classified according to acid stress, sensitivity, and fish community.

The results indicate that up to 350,000 hectares of lakes (16,000) are in areas where the precipitation pH is low and the lake waters poorly buffered. The lakes in this condition mostly contain salmonid dominated fish communities, lake trout, Salvelinus namaycush, and/or brook trout. If these lakes are acidified to the point where they are incapable of sustaining fish communities, Ontario stands to lose more than 30 percent of some key salmonid fisheries.

Among the 16,000 lakes, there are 4,600 which must be considered as being already acidified. Many of these lakes are small and are in the Sudbury-La Cloche region, where previous studies have identified many larger lakes as having been acidified, predominately as a result of local smelter operations.

1982 - Current status of lake acidification and its effect on the fishery resources of Canada. See under KELSO, J.R.M.

1983 - Effect of fluctuating lead exposures on lead accumulation by rainbow trout (Salmo gairdneri). See under HODSON, P.V.

MINNS, C.K (cont.)

1983 - The effects of fluctuating concentrations of waterborne contaminants on their uptake by fish - implications for water quality monitoring. See under HODSON, P.V.

1984 - Analysis of lake and drainage area counts and measures for selected watersheds across Ontario's Shield region. Can.MS Rept.Fish. Aquat.Sci., (1748).

This report provides a summary and analysis of lake area, drainage area, and lake order data from 30 watersheds in Ontario. The data are compared with previous counts and measures data. The total dataset is compared to the subset of lakes that have been inventoried for their fish assemblage by the Ontario Ministry of Natural Resources.

The results show that this data is similar to that collected previously and that inventory selection is biased toward larger lakes and against headwater systems.

1984 - Spatial and temporal variability in zooplankton abundance of the Great Lakes. Can.MS Rept.Fish.Aquat.Sci., (1750).

Data from several surveys of zooplankton distribution and abundance in the Great Lakes are summarized to give total biomass, and cladoceran, calanoid, and cyclopoid abundance. The summaries by station and cruise are analyzed to examine the relative importance of, and significance of spatial and temporal variability. The results are assessed and their relevance to the design of future zooplankton studies examined.

1984 - with COOLEY, J.M., & FORNEY, J.E. Analysis of the response to the use of 'adaptive environmental assessment methodology' by the Great Lakes Fishery Commission. Great Lakes Fish.Comm., Spec.Publ., (84-3).

Through its Board of Technical Experts (BOTE), the Great Lakes Fishery Commission sponsored an extensive trial of the Adaptive Environmental Assessment Methodology (AEAM), a workshop/modelling technique which has been developed over several years at the Institute of Animal Resource Ecology, UBC and at IIASA, Austria. The workshop modelling exercises are used to identify data and conceptual weaknesses in the collective understanding of how complex systems operate and to allow an exploration of the effects of alternate management strategies. The trial consisted of a training course for modellers and three workshops focussed on Great Lakes problems, lake trout rehabilitation, sea lamprey control, and fishery management. After the workshops, it was decided there should be a review of the whole exercise.

A committee of BOTE was charged with the task of reviewing the workshops and the AEA process. The committee used questionnaires to guage the opinions and reactions of workshop participants and of fishery agency managers who are the primary clients for such workshops. The printed reports on workshops were also reviewed.

The results showed that overall there was a majority of support among participants and clients for the past and future potential uses of AEA methodology. The results also highlighted areas where

MINNS, C.K. (cont.)

the workshops and their impact could be significantly improved e.g. by tackling smaller problems, more preparation before the workshop, greater involvement of participants in all phases of a workshop, more analysis of uncertainties and less of the models, and a greater effort to communicate the results to decision makers whether in research-planning or management.

Clearly, there is a strong mandate for further use of the AEA process by the Commission and its collaborating agencies.

1985 - A workshop concerning the application of integrated pest management (IPM) to sea lamprey control in the Great Lakes. See under SPANGLER, G.R.

1986 - Acid rain: a further estimate of the risk to Ontario's inland fisheries. Can.MS Rept.Fish.Aquat.Sci., (1874).

The databases of lake inventory and chemistry have substantially increased from Minns (1981). There has also been progress in evaluating the biases in the databases. A methodology is presented for extrapolating from a comprehensive database of inventory and chemistry data via the larger lake inventory database, to the total resource of lakes in the province of Ontario. This 'scaling-up' is done for lakes regardless of fish species and for the lakes containing one of four gamefish species - brook trout, lake trout, smallmouth bass and walleye.

The results suggest there are more than 3,200 lakes in Ontario with an alkalinity less than zero and nearly 16,000 lakes with an alkalinity between 0 and 50 $\mu eq.l^{-1}$. There are few gamefish lakes with alkalinities less than zero but large portions of gamefish resources are found in lakes with alkalinities less than 50 $\mu eq.l^{-1}$. Most of the lakes with alkalinities less than 50 $\mu eq.l^{-1}$ are located in watersheds bordering the upper Great Lakes where acid deposition is greatest.

The results obtained here do not differ substantially from results reported by Minns (1981).

1986 - An inspection of the New Zealand freshwater fish survey data base. N.Z.Min.Agric.Fish., Fish.Res.Div., Intern.Rept., (43). (Unpubl.).

The work described in this report was carried out while the author was in receipt of a Senior Fellowship from N.Z. National Research Advisory Council.

1986 - A model of bias in lake selection for survey. Can.Techn.Rept. Fish.Aquat.Sci., (1496).

The purpose of this report is to describe the results of analyses of the Ontario lake inventory data base. Models of selection bias are developed from a model of predator preference. The models are used to estimate the selection bias toward lakes containing four gamefish species, brook trout, lake trout, smallmouth bass, and walleye. The results suggest that the co-occurences of these species are overrepresented in the data base and that unsurveyed lakes, if they have gamefish, will likely only have one of the four species present. Alternative schemes for eliminating or accommodating the biases are discussed.

1986 - Fish species assemblage structure in Ontario's lakes. Can.MS Rept.Fish.Aquat.Sci., (1898).

The fish species associations found in Ontario's lakes are clustered using Ochiai's association index. A number of species groupings are identified. They tend to be dominated by large gamefish species (top predators). Attempts to discriminate lake types based on the fish assemblages were no more successful than attempts based on the presence/absence of top predators. The species groupings are consistent with the Ryder and Kerr concept of harmonic communities though incompleteness of fish species lists, especially small and uncommon species, prevented a finer discrimination of assemblages.

1986 - A simple whole-lake phosphorus model and a trial application to the Bay of Quinte. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can.Spec.Publ.Fish.Aquat.Sci., (86):84-90.

A simple whole-lake phosphorus model is presented. Coupled mass balance equations for the water column and surface sediment phosphorus pools in a lake are described. The model is shown to be a descendant of the Vollenweider model. The concept of 'apparent settling velocity' is replaced with an operationally defined concept determined by sedimentation, reflux (internal loading), and permanent deposition rates. The model is used in an analysis of the Bay of Quinte phosphorus budgets. The dominance of internal loading is supported. The effect of uncertainty in key model parameters is shown. Use of the model for evaluation of lakes with changing phosphorus loads is recommended. Where reflux from the surface sediment pool is present, the response of lake water quality, as determined by phosphorus concentrations in the water column, will lag changes in external phosphorus loading rates. When external loading increases, the sediment pool retains phosphorus and minimizes the impact on water quality until it comes to steady state. When external loading decreases, the sediment pool delays the improvement in water quality because of reflux.

1986 - Total phosphorus loading to the Bay of Quinte between the years 1800 and 2000: a model study. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can. Spec.Publ.Fish.Aquat.Sci., (86):77-83.

The models generally used, such as Vollenweider's, to evaluate eutrophication in lakes and bays cannot be used on the Bay of Quinte because of its extreme morphometry and hydrology. Another simple model is developed which uses population growth in urban centres and in the watershed to predict changes in river and point-source loadings of phosphorus. The role of the variable runoff is examined. Predicted annual loads and mean summer input concentrations are

MINNS, C.K.(cont.)

consistent with available data. The model demonstrates the importance of controlling point sources and shows how loading escalated after the 1940's because of increasing urban populations and the use of phosphate detergents. The model also shows how the control measures, first the reduction of P in detergents and then installation of testing treatment, greatly reduced point-source inputs. The model shows how low summer flows and high point-source inputs produce excessive P concentrations in the summer and demonstrates the importance of consistent control for the preservation of water quality. If all P removal facilities are operated efficiently, it is predicted that summer P concentrations in the Bay of Quinte will be kept below 50 $\mu g.l^{-1}$ well into the next century, under most flow conditions.

1986 - with HURLEY, D.A. Population dynamics and production of white perch, Morone americana, in the Bay of Quinte, Lake Ontario. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can.Spec.Rept.Fish.Aquat. Sci., (86):215-223.

All available data on the 1950's invasion and proliferation of white perch (Morone americana) in the Bay of Quinte, a freshwater embayment of Lake Ontario, are analyzed and summarized. The life history parameters are shown to be similar to those for this species in its native habitat, Atlantic estuaries and lakes in the northern part of its range. Seasonal movements within the bay are linked to spawning, feeding, and overwintering. The population expanded from the time of its invasion until the early 1970's, when the commercial fishery brought about a slight decline, followed by a climate-related crash in late winter of 1978. Density-dependent growth is clearly demonstrated. Estimates of egg production and survival to age 1 are made, and biomass and production calculated. A simple simulation model is constructed to test the consistency of the analyses. Early survival estimates are found to be the weak link, primarily because of insufficient data. Available evidence suggests that reduced piscivore abundance, perhaps due to eutrophication, allowed the white perch to proliferate in the bay, where they appear well suited to conditions which are estuarine-like. Recently, it appeared that biomass was declining under the stress of the combined action of a low temperature kill and a resurgence of piscivores, particularly walleye (Stizostedion vitreum vitreum). Increased piscivore abundance should prevent white perch recovering to previous levels.

1986 - with JOHNSON, M.G. Temperature and oxygen conditions and oxygen depletion in the Bay of Quinte, Lake Ontario. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can.Spec.Publ.Fish.Aquat.Sci., (86):40-49.

The summer temperature and oxygen regimes throughout the Bay of Quinte between 1972 and 1983 are described. Oxygen depletion rates at stations in the lower bay are calculated and analyzed. The link between oxygen depletion and eutrophication is examined. Oxygen

MINNS, C.K.(cont.)

depletion did not respond to decreased point-source phosphorus loading. There was little evidence of change of trophic state in the lower bay, and oxygen depletion rates were consistent. Oxygen depletion rates were not related to hypolimnetic temperature or warming rates.

1986 - with KELSO, J.R.M. Estimates of existing and potential impact of acidification on the freshwater fishery resources and their use in eastern Canada. Wat.Air Soil Pollut., 31:1079-1090.

There are over 700,000 lakes in Canada, east of the Ontario-Manitoba border and south of latitude 52. This region supports much of Canada's freshwater fishery resources, mostly in acid-sensitive habitat. Of these lakes, half have alkalinities less than 50 $\mu eq.L^{-1}$ and 150,000 have a pH less than 6. There are 14,000 acidic lakes i.e., with a pH less than 4.7.

Models of lake-watershed systems have been developed to predict the future response of fishery resources in eastern Canada. Despite considerable uncertainties in key parameters, the predicted range of losses is not great. The models predict that with current acid deposition, up to 9 percent of all lakes will ultimately have a pH less than 5. Reduction of deposition rates, either by 40 percent everywhere or to a maximum of $12kg.ha^{-1}SO_4$, greatly reduces the predicted losses. The models give conservative predictions of impact as inclusion of loss of watershed acid neutralizing capacity and fish mortality due to episodic pH depression would indicate greater losses. The freshwater fishery resources of eastern Canada are important economically, accounting for 42×10^6 angler-days and $\$1.4 \times 10^9 yr^{-1}$ per year. Up to 10 percent of this sector of the Canadian economy could be at risk.

1986 - with D.A.HURLEY & K.H.NICHOLLS(eds.). Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can.Spec.Publ.Fish.Aquat.Sci., (86). 270pp.

1986 - with KELSO, J.R.M., & JOHNSON, M.G. Large-scale risk assessment of acid rain impacts on fisheries: models and lessons. Can.J.Fish. Aquat.Sci., 43:900-921.

Lakes, streams, and their watersheds in large parts of the world have little ability to neutralize acidity associated with precipitation. Resource management agencies are concerned with the extent of these impacts including the loss/hazard to key fish species, and the likely status of these aquatic systems given alternate emission control scenarios. Two models designed to provide such a large-scale risk assessment are presented herein. The strengths and weaknesses are identified. Since models draw together the best of our theories, experimental, and survey data, these are compared with existing knowledge, theories, and data.

1986 - with OWEN, G.E., & JOHNSON, M.G. Nutrient loads and budgets in the Bay of Quinte, Lake Ontario, 1965-81. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte, Lake Ontario. Can.Spec.Publ.Fish.Aquat.Sci., (86):59-76.

MINNS, C.K.(cont.)

The Bay of Quinte is a eutrophic bay at the eastern end of Lake Ontario where point-source phosphorus loadings were greatly reduced from 1978 onwards. Loadings and budgets for phosphorus, nitrogen, and chloride are presented for the period 1965-81. Whole-bay and sectional budgets are examined, including the effect of exchange flows with Lake Ontario. By calculation, the role of internal loading is examined. The point-source phosphorus loadings have decreased dramatically, while nitrogen and chloride are little changed. The upper bay budgets are dominated by internal loading, and a 'catastrophe' model is proposed to describe its behaviour. In the upper bay, there has been a shift from external to internal loading control. In the lower bay, the budgets are dominated by a 'nutrient pump', such as that seen in estuaries, driven by the exchange flows with Lake Ontario. Overall, while significant water quality improvements have been recorded, further improvements should be expected in the future as the internal loading dissipates and control is returned to external loading once again.

1986 - HURLEY, D.A., CHRISTIE, W.J., MINNS, C.K., MILLARD, E.S., COOLEY, J.M., JOHNSON, M.G., NICHOLLS, K.H., ROBINSON, G.W., OWEN, G.E., SLY, P.G., GEILING, W.T., & CROWDER, A.A. Trophic structure and interactions in the Bay of Quinte, Lake Ontario, before and after point-source phosphorus control. In; C.K.MINNS, D.A.HURLEY & K.H.NICHOLLS(eds.), Project Quinte: Point-Source Phosphorus Control and Ecosystem Response in the Bay of Quinte. Lake Ontario. Can.Spec.Publ.Fish.Aquat.Sci., (86):259-270.

Project Quinte data are used to test several hypotheses to explain the observed changes in the Bay of Quinte that occured as nutrient loading increased up to the mid-1970's and as loads decreased after 1977. The nutrient hypothesis states that the bay condition is a direct result of excessive phosphorus inputs. The predation hypothesis states that changing predator-prey relationships result in the same conditions seen when phosphorus inputs are excessive. The succession hypothesis states that the condition of the bay ecosystem results when the orderly, directional stages of development are stressed by nutrient additions and other stress factors that surpass the resilience of the system. Each hypothesis partially explains the data, but transitions, especially in phytoplankton-zooplankton interactions, do not fit the hypotheses well. A size-spectrum model of biomass predicts that the biomass of small zooplankton is greater than expected, while that for small fish is smaller than expected. This model predicts that the transfer of biomass is being restrained and that the ecosystem is not at a steady state. The Bay of Quinte is compared with other areas in the Great Lakes basin that receive less and more nutrients at the present time. Several guidelines are presented by which the rehabilitation of the Bay of Quinte, and other areas in the Great Lakes basin, can be assessed.

1986 - Acidification of surface waters in eastern Canada and its relationship to aquatic biota. See under KELSO, J.R.M.

1986 - Headwater lake chemistry during the spring freshet in north-central Ontario. See under KELSO, J.R.M.

MOORE, J.E.

1972 - The seasonal cycle of pheo-pigments in Lake Ontario with particular emphasis on the role of zooplankton grazing. See under GLOOSCHENKO, W.A.

1973 - Surface distribution of chlorophyll a and primary production in Lake Huron, 1971. See under GLOOSCHENKO, W.A.

1973 - The effect of citrate on phytoplankton in Lake Ontario. See under GLOOSCHENKO, W.A.

1973 - Chlorophyll a distribution in Lake Huron and its relationship to primary production. See under GLOOSCHENKO, W.A.

1974 - STADELMANN, P., & MOORE, J.E. Measurement and prediction of primary production at an offshore station in Lake Ontario. Fish. Res.Bd.Can., Techn.Rept., (445).

Photosynthesis rates using the ^{14}C technique were measured in situ in Lake Ontario and simultaneously in a shipboard incubator. There was good agreement between maximum in situ photosynthesis rate and that obtained in the incubator. Empirical factors were computed by comparing the photosynthesis rate obtained during a 4 hr. experiment (10 A.M. - 2 P.M.) with that for the whole daylight period. This relation showed that 36-58 percent of the daily production occured during this 4 hr. eriod. At an offshore station annual production was estimated (185 g C $m^{-2}year^{-1}$).

Daily photosynthesis rates using the 'reference integral' method were computed and compared with in situ daily rates; both methods gave similar values.

1974 - STADELMANN, P., MOORE, J.E., & PICKETT, E. Primary production in relation to temperature structure, biomass concentration, and light conditions at an inshore and offshore station in Lake Ontario. J.Fish.Res.Bd.Can., 31:1215-1232.

Annual primary production rates of 270 and 170 g c m^{-2} yr^{-1}, respectively, were estimated for an inshore and offshore station in Lake Ontario using the in situ ^{14}C technique. A lag in increase of both biomass and photosynthesis rate at the offshore station in early summer was attributed to deep vertical mixing.

Production/biomass quotients were computed using different biomass parameters such as particulate organic carbon, nitrogen, and chlorophyll a. Carbon turnover rates of the seston on an areal basis (m^2) were found to vary between 0.04-0.18 day^{-1} and 0.01-0.21 day^{-1} at the inshore and offshore station, respectively. Daily photosynthesis efficiency (energy fixed by photosynthesis/available energy) ranged from 0.1 to 1.8 percent at the two stations. Atypical photosynthesis-light intensity curves showed that algal populations behaved differently at different depths during the stratified period.

1974 - Spatial and temporal distribution of chlorophyll a and phaeopigments in surface waters of Lake Erie. See under GLOOSCHENKO, W.A.

MOORE, J.E. (cont.)

1974 - Primary production in Lakes Ontario and Erie: a comparative study. See under GLOOSCHENKO, W.A.

1977 - with LOVE, R.J. Effect of a pulp and paper mill effluent on the productivity of periphyton and phytoplankton. J.Fish.Res.Bd.Can., 34:856-862.

The short-term effect of a kraft mill effluent on the productivity of periphyton and phytoplankton in Nipigon Bay was examined. Addition of raw effluent at concentrations of 10^{-2} and higher consistently reduced photosynthesis of both periphyton and phytoplankton. Significant reductions were occasionally observed at effluent concentrations as low as 10^{-4}. At high effluent concentrations pH change produced a major portion of the depression. Laboratory experiments with four compounds identified from the effluent showed dehydroabietic acid to be slightly toxic.

1980 - Measurement of particulates entrained in some Great Lakes power plant cooling water: an exercise in futility. See under LESLIE, J.K.

1983 - Phytoplankton production as estimated by the C^{14} technique, and populations contributing to production 1980/81/82, in the Turkey Lakes, Ontario, watershed. See under COLLINS, R.H.

1983 - Seine for sampling larval fish in shallow water. See under LESLIE J.K.

1984 - Zooplankton and potential fish production in Lake Ontario. See under BORGMANN, U.

1985 - Ecology of young-of-the-year fish in Muscote Bay (Bay of Quinte), Ontario. See under LESLIE, J.K.

1985 - Lake Ontario long term biological monitoring program: report for 1981 and 1982. See under JOHANNSSON, O.E.

1985 - Lake Ontario long term biological monitoring program: 1981, 1982 data base. See under JOHANNSSON, O.E.

1986 - Population dynamics, biomass, and production of the macrozooplankton in the Bay of Quinte during changes in phosphorus loadings. See under COOLEY, J.M.

1986 - Changes in the lengths of fixed and preserved young freshwater fish. See under LESLIE, J.K.

1986 - Zooplankton abundance in the Bay of Quinte, 1975-1976. Can.Data Rept.Fish.Aquat.Sci., (596).

Zooplankton adult and egg abundance estimates are presented based on the results of an extensive series of sample collections made at several locations in the Bay of Quinte (Lake Ontario) during 1975 and 1976.

MOORE, J.E.(cont.)

Temperature profile data obtained at the same locations and times are also presented.

1986 - Zooplankton abundance in the Bay of Quinte, 1979-1984. Can.Data Rept.Fish.Aquat.Sci., (597).

Zooplankton adult and egg abundance estimates are presented based on the results of an extensive series of sample collections made at several locations in the Bay of Quinte (Lake Ontario) during the period 1979 to 1984.

Temperature profile data obtained at the same locations and times are also presented.

MUNAWAR, M.

1971 - with NAUWERCK, A. The composition and horizontal distribution of phytoplankton in Lake Ontario during the year 1970. Proc.14th. Conf.Great Lakes Res.1971:69-78.

Surface samples of phytoplankton were collected from January to December, 1970, at approximately 4-week intervals from 27-30 stations distributed over the entire lake. Taxonomic identification and enumeration was done by the Utermöhl technique. The data are presented as cell volume (μ^3/ml). The cruise averages for all the stations showed only one clearly pronounced maximum in the middle of summer. Diatoms were responsible for about 80 percent of the volume during winter and spring. Green algae were the most dominant during the summer and fall maximum. Diatoms, cryptomonads and green algae, in that order, were the most important constituents of the lake phytoplankton. Phytoplankton biomass showed low densities but homogeneous distribution in the central part of the lake, whereas high densities and irregular distribution were observed in the inshore regions. A general tendency towards single-peak development in the central areas and towards repeated pulses in the inshore regions was noticed. The average biomass of the inshore region was about 25 percent greater than that of the offshore region. The seasonal development of the phytoplankton biomass exhibited a marked inshore to offshore trend in spring. Regions of major inputs of nutrients and regions of upwelling were often found to be richer in plankton. Prominent perennial species were *Rhodomonas minuta* Skuja, *Cryptomonas erosa* Ehrnb., *Katablepharis ovalis* Skuja, *Ankistrodesmus falcatus* var. *spirilliformis* G.S.West, *Scenedesmus bijuga* var. *irregularis* G.M.Smith, *Chroococcus dispersus* var. *minor* G.M.Smith and *C.minutus* Kg. Among the common species *Melosira binderana* Kg. was the most important one with its development closely related to the thermal bar. *Chrysochromulina parva* Lackey was the only chrysomonad of quantitative significance showing a summer-through-fall distribution. *Rhodomonas minuta* Skuja was a year round species showing a late-summer maximum development.

1972 - with VERDUIN, J., & MUNAWAR, I.F. Primary production studies in shallow aquatic environments of southern Illinois. Verh.Internat. Verein.Limnol., 18:113-120.

MUNAWAR, M.(cont.)

Extensive studies have been made during the past 15 to 20 years to determine the primary productivity of freshwater environments. However, these studies were confined to relatively deep bodies of water (>1 meter) such as lakes and reservoirs. Consequently, very little information is available about shallow aquatic environments (~1 decimeter) where there is not much differentiation of the water column into various strata as a result of thorough mixing. Another aspect of production which has been neglected is that of primary productivity under completely natural conditions. Data are scant in the literature regarding production under completely natural conditions, although studies made by some previous authors represent near natural conditions.

In the present investigations, primary production studies were made on shallow aquatic environments located on the campus of Southern Illinois University, and the investigations included the collection of data under completely natural conditions as well as experiments using light and dark bottles. The need was also recognized to make these studies quite frequently and extensively, sampling at least three times a week and three times a day for an extensive period of observation and utilizing more than one procedure. Consequently, the present work was carried out by means of two techniques followed simultaneously, i.e., using a pH meter to follow CO_2 changes and an oxygen probe to follow O_2 changes.

1973 - A comparison of electronic particle counters and inverted microscope methods for counting phytoplankton. See under LESLIE, J.K.

1974 - A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. See under VOLLENWEIDER, R.A.

1974 - STADELMANN, P., & MUNAWAR, M. Biomass parameters and primary production at a nearshore and a midlake station of Lake Ontario during IFYGL. Proc.17th.Conf.Great Lakes Res.1974:109-119.

The seasonal variation of particulate organic carbon (POC) and nitrogen (PON), particulate phosphorus (PP), chlorophyll a, adenosine triphosphate (ATP) and phytoplankton biomass was investigated at a nearshore and a midlake station in Lake Ontario during IFYGL. Photosynthesis rates using the ^{14}C technique were measured on two consecutive days at each station and related to the various biomass parameters. At the nearshore station, the mean concentration (in the 0-10 m zone) of various biomass parameters varied from 130-960 POC mg/m^3, 20-180 PON mg/m^3, 1.5-13.5 PP mg/m^3, 0.7-9.8 Chl a mg/m^3, 0.07-0.81 ATP mg/m^3 and 220-2800 algal biomass mg/m^3, respectively. High values were shown by all the parameters in June and July.

The midlake station showed a lag in biomass increase during spring and the maxima were observed later in July and September. The concentrations ranged between 80-720 POC mg/m^3, 10-140 PON mg/m^3, 2.1-10.6 PP mg/m^3, 0.9-8.5 Chl a mg/m^3, 0.03-1.85 ATP mg/m^3, and 200-1700 algal biomass mg/m^3.

On comparing averaged values the nearshore station showed approximately 50 percent more POC, PON, PP and Chl a and 100 percent more phytoplankton biomass, whereas both stations exhibited similar

MUNAWAR, M.(cont.)

ATP values. Carbon turnover rates were computed for depth where maximum daily photosynthesis was observed, using sestonic carbon (POC), algal carbon (phytoplankton biomass X 0.1) and living carbon (ATP X 250). The turnover rates at the midlake station varied between 0.04-0.46 day^{-1} and 0.37-1.92 day^{-1} and 0.35-1.99 day^{-1} based on POC, phytoplankton biomass and ATP, respectively. The corresponding values for the nearshore station ranged between 0.08-0.38, 0.49-2.71 and 0.79-2.89 day^{-1}.

The comparison of various biomass parameters determined in this study indicated that a significant amount of detritus is present over the entire year at both stations.

1974 - with STADELMANN, P., & MUNAWAR, I.F. Phytoplankton biomass, species composition and primary production at a nearshore and a midlake station of Lake Ontario during IFYGL. Proc.17th.Conf.Great Lakes Res.1974:629-652.

As a part of the Canadian contribution to the International Field Year for the Great Lakes (IFYGL), qualitative and quantitative analyses of phytoplankton were carried out at a nearshore and a midlake station. Samples were collected on two consecutive days by an integrating sampler (0-10 m) during nine cruises extending from April 1972 to March 1973. Simultaneously, chlorophyll a samples were taken, and carbon-14 uptake was measured in an incubator. About 100 taxa were identified in samples from each station and contained several phytoflagellates and 'less common' species neglected in other IFYGL investigations. On a biomass basis the 'less common' species contributed significantly to the total phytoplankton biomass. The dominance of phytoflagellates for most of the year at both stations was striking. Similarly, nannoplankton (<64 μ) dominated the phytoplankton at both stations throughout the study period. At times more than 85 percent of the total photosynthesis was due to the nannoplankton fraction.

At the nearshore station, phytoplankton biomass and chlorophyll a ranged from 0.2 to 2.3 g/m^3 and 1.9 to 8.0 mg/m^3 respectively. Whereas the primary production rate fluctuated between 2 and 23 mg C_{ass} m^{-3} hr^{-1}. The biomass maximum developed earlier at the nearshore station due to the formation of a thermal bar. High biomass (1.7 g/m^3) and primary production rates (15 mg C_{ass} m^{-3} hr^{-1}) were observed during spring and summer, when phytoflagellates contributed from 60 to 70 percent to the total biomass.

At the midlake station, the phytoplankton biomass and chlorophyll a ranged from 0.2 to 1.6 gm^{-3} and from 1.0 to 7.7 $mg.m^{-3}$ respectively, whereas, the primary production rate ranged between 1.4 and 31.5 mg C_{ass} m^{-3} hr^{-1}. No spring maxima developed at the midlake station, instead the maxima developed a month later in July. This lag in biomass increase is attributed to deep mixing and low temperatures. Highest values of phytoplankton biomass (1.5 gm^{-3}) and primary production rate (25 mg C_{ass} m^{-3} hr^{-1}) was observed during summer when phytoflagellates contributed from 65 to 77 percent to the total biomass.

On a volumetric basis, the production/biomass quotient (activity coefficient) ranged between 0.002 to 0.026 hr^{-1} and 0.002 to 0.02

MUNAWAR, M.(cont.)

hr^{-1} at the nearshore and midlake stations respectively. At both the stations P/B quotients were observed in September when diatoms were extremely low but dinoflagellates, green algae and cryptomonads, in that order, were the dominant algal groups.

Similarly, phytoflagellates dominated when high photosynthetic efficiency (energy fixed/available energy) was observed at both the stations during summer. Nutrient depletion (soluble reactive phosphorus, soluble reactive silicate and soluble inorganic nitrogen) was apparent at both the stations during phytoplankton pulses. Particularly, silica depletion from 410 to 36 and from 447 to 34 SiO_2 µg/l was most striking at the nearshore and midlake stations respectively. Phytoplankton biomass was correlated better with chlorophyll a and photosynthesis rates than the cell surface area. No correlation of biomass was obtained with cell numbers, suggesting the necessity to express phytoplankton population data as biomass. Under stratified conditions maximum phytoplankton biomass, chlorophyll a and primary production was observed in the mid-thermocline region where phytoflagellates were the dominant phytoplankton.

1974 - Primary production in Lakes Ontario and Erie: a comparative study. See under GLOOSCHENKO, W.A.

1974 - SHEATH, R., & MUNAWAR, M. Phytoplankton composition of a small subarctic lake in the Northwest Territories, Canada. Phycologia, 13(2):149-161.

Eighty-one common taxa were identified from a subarctic lake near Norman Wells, N.W.T., during the summers of 1972 and 1973. Many of these organisms were ephemeral in distribution. The Diatomeae, Chlorophyta and Cyanophyta accounted for 84 percent of the total taxa and the dominating morphological forms were nonmotile unicells and colonies. Comparing these results with other arctic and subarctic lakes it seems that the diversity of taxonomic groups and morphological forms is not restricted by increasing latitudes. The ratio of net plankton-to-nannoplankton was 0.72 with the largest nannoplanktonic group being the 21-40 µm size category. Based on species composition (31 percent of the species indicating eutrophy), phytoplankton quotients, such as the Myxophycean, Chlorophycean and Compound Quotients, along with the high nutrient levels, it was postulated that the lake was possibly eutrophic.

1974 - LOREFICE, G.J., & MUNAWAR, M. The abundance of diatoms in the southwestern nearshore region of Lake Ontario during the spring thermal bar period. Proc.17th.Conf.Great Lakes Res.1974:619-628.

As a part of the IFYGL program an intensive study was carried out during April and May 1972 in the nearshore region of Lake Ontario. Water samples were collected from 45 stations on the southwestern nearshore area of Lake Ontario at 1/2, 4 and 8 kms. Using the Utermöhl technique, phytoplankton was analyzed qualitatively and quantitatively. During the investigation period the thermal bar remained within the study area. In April it stayed shoreward of the 4 kms stations, dipping into and out of the shore. By May it had advanced farther out but in most cases to less than 8 kms.

MUNAWAR, M.(cont.)

Total phytoplankton biomass along with diatoms, particularly Melosira binderana Kutz. showed high concentrations on the nearshore side of the thermal bar. This observation may be related to temperature and the concentration of nutrients in the nearshore region. Diatoms accounted for 58 percent of the biomass in April and 48 percent in May. During April Surirella angustata Kutz., Rhodomonas minuta Skuja and Peridinium aciculiferum (Lemm.) Lemm. were the most common species while M.binderana Kutz, P.aciculiferum and Melosira islandica ssp. helvetica O. Muller were common in May.

1975 - Problems in the monitoring of biomass. See under WATSON, N.H.F.

1975 - SHEATH, R.G., MUNAWAR, M., & HELLEBUST, J.A. Phytoplankton biomass composition and primary productivity during the ice-free period in a tundra Pond. Proc.Circumpolar Conf.North.Ecol., (3):21-31.

Phytoplankton succession in a shallow arctic pond near Tuktoyaktuk, N.W.T., (69°27'N, 133°00'W) was determined from June 6 to September 24, 1974. The biomass was low during ice-melt and was predominantly composed of Dinophyceae and Chrysophyceae. Many of these species were ephemeral in occurence and formed resting spores after one week as the water temperatures increased. During ice-melt and early summer the primary productivity was low but increased in mid-July (11.6 to 21.0 mgC m^{-2} day^{-1}). This was followed by a primary productivity minimum in mid-August and then by a peak on August 24 of 46 mgC m^{-1} day^{-1}. Phytoplankton biomass changes followed fairly closely the trends of primary productivity and it was observed that the Chrysophyceae were dominant during the maxima. Certain species, such as Botryococcus braunii and Rhodomonas minuta were present throughout the ice-free period and morphological changes were observed. Fluctuations in phytoplankton composition and biomass were related to changes in some environmental factors and the results of this study indicate certain interesting aspects of phytoplankton overwintering.

1975 - SHEATH, R.G., MUNAWAR, M., & HELLEBUST, J.A. Fluctuations of phytoplankton biomass and its composition in a subarctic lake during summer. Can.J.Bot., 53:2240-2246.

Phytoplankton biomass was determined for a shallow subarctic lake from June to August, 1973, with one peak being observed at the beginning of July (300 mg m^{-3}). Phytoplankton then declined until the end of August when a relatively high value of 240 mg m^{-3} was observed. The Chlorophyta and Diatomeae were the dominant taxa during periods of high biomass, whereas other algal groups had relative increases only during the minima. The early summer population was almost entirely composed of diatoms, followed by a mixed population of diatoms and cryptomonads, and then by the Chlorophyta, which dominated during midsummer. Subsequently, there were successive increases of chrysomonads, dinoflagellates, and then diatoms. Fluctuations of major species were examined in relation to changes in biomass of the algal groups. Net plankton species were dominant throughout most of the summer but nanoplankters were abundant for short periods in mid-June and July. Based on a few

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comparisons done in July, it was found that the species composition of phytoplankton was not similar to that of the benthic algae since only 15 percent of the species were common to both habitats and these species contributed to 21 percent of the phytoplankton biomass estimated.

1975 - with MUNAWAR, I.F. The abundance and significance of phytoflagellates and nannoplankton in the St.Lawrence Great Lakes. 1. Phytoflagellates. Verh.Internat.Verein.Limnol., 19:705-728.

The importance of phytoflagellates in the community structure, metabolism and food chain dynamics is well known. These delicate flagellates have a much greater influence upon the metabolic exchange throughout the epi- and metalimnion since they have a higher reproduction and decomposition rates and lower rates of sinking.

The present paper is intended to emphasize the abundance of phytoflagellates in the Great Lakes and to stress the need for adopting standard and universally accepted methods such as Utermöhl's inverted microscope procedure in all the investigations to produce comprehensive and comparable community structure information.

1975 - with MUNAWAR, I.F. Some observations on the growth of diatoms in Lake Ontario with emphasis on *Melosira binderana* Kütz during thermal bar conditions. Arch.Hydrobiol., 75(4):490-499.

The distribution of the diatom *Melosira binderana* Kütz, a species often associated with eutrophication, was investigated in Lake Ontario during 1970 and 1972 in relation to temperature structure, soluble reactive phosphorus and silicate during spring when a distinct thermal bar was formed. *Melosira binderana* showed a marked nearshore to offshore decreasing gradient and maximum densities were observed inside the thermal bar. Its abundance was related to nutrients and indirectly to temperature which controlled the circulation. Excessive growth of *M.binderana* depleted silicate to extremely low levels (25 SiO_2 µg 1) in the nearshore region.

1976 - with BURNS, N.M. Relationships of phytoplankton biomass with soluble nutrients, primary production, and chlorophyll *a* in Lake Erie, 1970. J.Fish.Res.Bd.Can., 33:601-611.

Comparison of the annual average distribution patterns of phytoplankton biomass, chlorophyll *a*, primary production, soluble reactive phosphorus, nitrate + nitrite, and ammonia concentrations revealed that these six variables had very similar distributions in Lake Erie during 1970. However, statistical analysis of the data only revealed a few consistent relationships between these variables. The phytoplankton biomass was correlated with chlorophyll *a* only in the summer and fall as was primary production with chlorophyll *a* and biomass. There was no correlation between these three variables during the spring. Also, there was no consistent relationship between biomass and soluble nutrients. The primary production and activity coefficient (mg $C_{assimilated}$ per milligram

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phytoplankton biomass per day) were found to be unrelated to temperature. The statistical procedure of factor analysis showed that in the spring, primary production correlated with the phosphorus and nitrogen soluble nutrients only, whereas during summer, primary production correlated with biomass, chlorophyll a, the major plankton groups (Cyanophyta, Chlorophyta, Chrysomonadinae, and Diatomeae), and the phosphorus nutrients. In the fall, production was positively correlated with phytoplankton biomass and with the Chlorophyta in particular. The use of chlorophyll a and temperature as variables in the equation to estimate phytoplankton growth in Lake Erie was found to be questionable.

1976 - with MUNAWAR, I.F. A lakewide study of phytoplankton biomass and its species composition in Lake Erie, April-December, 1970. J.Fish.Res.Bd.Can., 33:581-600.

Surface samples of phytoplankton were collected from April to December 1970 at approximately 4-week intervals from 25 stations distributed over the entire lake. Taxonomic identification and enumeration was done by the Utermöhl technique. About 125-150 species were identified in each basin. 'Less common' or rare species contributed significantly to the total phytoplankton biomass. The species comparison among the three basins indicated that species like Rhodomonas minuta and Cryptomonas erosa were perrenial in all the basins. Aphanizomenon flos-aquae, Anabaena spiroides var. contracta, Coscinodiscus rothii, Actinastrum hantzschii, and Ceratium hirundinella were typical for the western basin. Ochromonas spp. and Peridinium aciculiferum were common in the central basin whereas Gymnodinium helveticum and G.uberrimum were characteristic for the eastern basin.

The diatoms contributed least in the eastern basin (36 percent) but showed high percentage in both central (55 percent) and western (58 percent) basins. The phytoflagellates made important contributions in the three basins: highest percentage (41 percent) was in the eastern basin.

Phytoflagellate abundance increased from west to east and appeared to have a wide range of adaptability to different nutrient conditions. During July and August high biomass concentration but uneven horizontal distribution was observed. Phytoplankton biomass ranged between 0.8 and 13.2, 0.6 and 6.0, and 1.0 and 4.2 g/m^3 in the western, central, and eastern basins, respectively. The highest biomass of 13.2 g/m^3 was in the western basin during April. Inshore-offshore differentiation was observed in the central and eastern basins with many peaks in the inshore region. Size analysis of phytoplankton on a few stations showed that the nannoplankton ($\leq$64 μ) comprised a major portion of phytoplankton biomass during spring and fall periods. Based on maximum biomass concentration the Lake Erie western basin was classified as highly eutrophic, the eastern basin as mesotrophic, and the central basin between the mesotrophic and eutrophic conditions.

MUNAWAR, M.(cont.)

1976 - BURNS, N.M., JAQUET, J.-M., KEMP, A.L.W., LAM, D.C.L., LEACH, J.H., MUNAWAR, M., SIMONS, T.J., SLY, P.G., THOMAS, R.L., WATSON, N.H.F., & WILLIAMS, J.D.H. Processes within Lake Erie. J.Fish.Res.Bd. Can., 33:639-643.

The current level of knowledge concerning Lake Erie is inadequate for the development of a predictive model of the system. Nevertheless, an outline of the submodels required for the development of a predictive model is presented. Further, as a result of many recent studies, the level of understanding of the Lake Erie system has increased immensely and major gaps in the present knowledge of the lake have been identified; useful areas for future research have been indicated. Many of the recent studies of Lake Erie are included in this special issue. The results of these investigations have been summarized and linked together where possible, to describe the lake and give an overview of the more important processes in Lake Erie.

1978 - with MUNAWAR, I.F. Phytoplankton of Lake Superior, 1973. J.Great Lakes Res., 4(3-4):415-442.

The horizontal and vertical distribution of Lake Superior phytoplankton was studied from May to November/December 1973 at approximately monthly intervals from 34 stations distributed over the entire lake. Taxonomic identification and enumeration were carried out using the inverted microscope Utermöhl technique. The mean phytoplankton biomass showed a homogeneous distribution with very low biomass concentration across the lake (0.1 to 0.2 g/m^{-3}). It did not show any inshore/offshore differentiation, although relatively high values were observed in the western end. On a lakewide basis, the seasonal composition was dominated by the phytoflagellates (53 percent) and diatoms (38 percent), with the bluegreens and greens contributing the least. Among the phytoflagellates, Cryptophyceae (26 percent), Chrysophyceae (21 percent), and Dinophyceae (5 percent) were the main contributors.

Lake Superior is characterized by a large number of species. Approximately 285 taxa were identified, the majority of which have not been reported before in Lake Superior or other Laurentian Great Lakes. The offshore and open lake waters possessed large numbers of common species usually found in oligotrophic environments. However, the western end contained a limited number of common species, dominated by species of *Melosira* which are often associated with eutrophication. The offshore species succession revealed dominance of species usually found in oligotrophic waters. Several rare species were also identified. Some of them like *Stelexmonas dichotoma* Lackey and *Chrysolykos planctonicus* Mack were indicative of a cold-stenothermal oligotrophic environment. Vertical profiles exhibited three types of biomass-temperature relationships, one of which was the presence of a sub-thermocline maximum which appeared to be photosynthetically active. On the basis of biomass and species composition, Lake Superior was classified as an ultra-oligotrophic environment similar to the deep, large, oligotrophic, boreal lakes. Lake Superior results, once again, emphasize the significance of phytoflagellates and nannoplankton in the algal dynamics of the

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Laurentian Great Lakes and demand the application of the standard Utermöhl technique in all phycological investigations.

1978 - with WILSON, J.B. Phytoplankton-zooplankton associations in Lake Superior: a statistical approach. J.Great Lakes Res., 4(3-4) :497-504.

Very little is known about the multiple phytoplankton-zooplankton links in complex food chains. Lake Superior, with a zooplankton population dominated by herbivores, and a phytoplankton community consisting mainly of nannoplankton, is a unique environment for the study of plankton associations. Appropriate statistical techniques, including partial correlations, canonical correlations, and factor analysis, were used to analyse phytoplankton-zooplankton data collected concurrently on Lake Superior during 1973. The multivariate methods revealed more detailed, but less easily interpretable patterns than did the partial correlations. Over the entire sampling season, canonical correlation and factor analysis produced three significant roots and three multi-variate factors respectively. Temperature was a strong first factor and a root variable during the stratified period. The proposed statistical approaches might serve as powerful tools to explore the apparent relationships between trophic levels. The application of such analyses to comparisons of plankton associations in lakes of varying trophy may prove a useful avenue of research.

1978 - with MUNAWAR, I.F., CULP, L.R., & DUPUIS, G. Relative importance of nannoplankton in Lake Superior phytoplankton biomass and community metabolism. J.Great Lakes Res., 4(3-4) :462-480.

The qualitative and quantitative significance of nannoplankton in Lake Superior in terms of taxonomy and primary production was studied during 1973. The size analysis of algae into net plankton (≥64 μm) and nannoplankton (<64 μm) and its various size fractions (<5; 5-10; 10-20; 20-44; 44-64 μm) was based on microscopic enumeration and measurements by means of the Utermöhl procedure. Primary production experiments and their subsequent fractionation by means of carbon-14 technique were undertaken to determine the relative photosynthetic rate of different size fractions of algae. Production/biomass quotients (activity coefficients) were computed and related to species composition. On a lakewide basis, the nannoplankton was the major component of the algal biomass contributing from 57 to 80 percent and comprised mainly of Cryptophyceae, Diatomeae, and Chrysophyceae. Nannoplankton were also abundant vertically. The most common nannoplankton were: Chlorella sp., Scenedesmus bijuga (Turp.) Lagerheim, Ochromonas spp., Chrysochromulina parva Lackey, Chrysocapsa sp., Chromulina elegans Doflein, Cyclotella comta (Ehr.) Kütz., C.ocellata Pant., C.bodanica Eulen., Asterionella formosa Hass., Rhodomonas minuta Skuji, R.minuta var. nannoplanctica Skuja, Cryptomonas erosa Ehr., C.marsonii Skuja, Katablepharis ovalis Skuja, and Gymnodinium spp.

The nannoplankton also dominated the community metabolism by contributing, on an average, 87-94 percent to the primary production as demonstrated by carbon-14 fractionation experiments. The smallest

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size fraction of the uptake experiments (<10 μm), consisting of μ-algae and ultraplankton, was the most active fraction photosynthetically, contributing 72 percent to the total production. The Lake Superior algae were rich in chlorophyll content and were relatively efficient when compared to the lower Great Lakes as indicated by high production/biomass (P/B) and chlorophyll-biomass ratios. The cryptomonad species like Rhodomonas minuta, Cryptomonas erosa, C.marsonii, and the diatom Asterionella formosa showed extremely high P/B quotients. These results emphasize the importance of adopting the Utermöhl technique and a fractionation approach both in taxonomic and physiological research to focus on the complex nannoplankton ecology which clearly plays a key role in population dynamics.

1978 - MATHESON, D.H., & MUNAWAR, M. Lake Superior basin and its development. J.Great Lakes Res., 4(3-4):249-263.

Lake Superior is unique in having the largest surface area of any freshwater lake in the world; in volume it is second only to Lake Baikal. Its location on the edge of the Canadian Shield, in a rugged land and in a northern climate, has delayed and limited the cultural development of the basin. Natural loadings to the lake are small since the bedrock is resistant to weathering; man-made pollution is slight because of the low population density in the watershed. The lake surface occupies more than one-third of the basin area with the result that direct precipitation on the lake surface is the major source of water input. Atmospheric transport is considered to be one of the most important sources of chemical loadings, the ultimate origin of which may be quite removed from the watershed.

The present state of our knowledge about the Lake Superior basin is reviewed from several points of view which include the historical, geological, physical, chemical and biological aspects. It is apparent that the influence of man-made pollution has not yet affected the lake-wide water quality, and most of the lake remains in a largely unaltered oligotrophic condition.

In 1972, the two bordering countries, Canada and United States, entered into an agreement aimed at preserving this major resource. During 1976 the International Joint Commission received a report which described the baseline water quality conditions of the lake. This report provides much of the information on which managerial practices in the basin will be based during the next decade.

1978 - BISTRICKI, T., & MUNAWAR, M. A rapid preparation method for scanning electron microscopy of Lugol preserved algae. J.Microscopy, 114 (2):215-218.

A method that utilizes samples preserved and stored in Lugol solution is described. The samples are postfixed in osmium tetroxide, rapidly dehydrated in absolute ethanol and dried by the critical point drying technique. Aliquots of several samples can be processed simultaneously. Surface details of algae stored in Lugol and processed by this method are comparable to those found in conventional preparative procedures. No loss of nannoplankton or other small sized fractions have been observed.

MUNAWAR, M.(cont.)

1978 - EL-SHAARAWI, A., & MUNAWAR, M. Statistical evaluation of the relationships between phytoplankton biomass, chlorophyll a, and primary production in Lake Superior. J.Great Lakes Res., 4(3-4):443-455.

Phytoplankton biomass, chlorophyll a and primary production data collected during 1973 from Lake Superior were statistically analyzed using different regression techniques. The pattern of the spatial and temporal variabilities displayed by these parameters was determined. The analysis resulted in dividing the lake into three regions based on phytoplankton biomass and chlorophyll a, whereas two regions were found for primary production.

The relationship between the biomass and chlorophyll a was highly significant but the degree of significance varied by season. The variability in the chlorophyll a concentration was found closely related to the changes in the relative abundance of various taxonomic groups of phytoplankton.

1979 - with BISTRICKI, T. Scanning electron microsopy of some nannoplankton cryptomonads. Scanning Electron Microscopy, 3:247-260.

The identification of nannoplankton cryptomonads using light microscope techniques is not always accurate, because many details, which may differentiate species, are beyond the resolution of glass optics. A scanning electron microscopic study was carried out with cryptomonads such as Rhodomonas, Cryptomonas, Chroomonas and Katablepharis, which are common in the St.Lawrence Great Lakes. Scanning electron microscopy revealed diverse morphological features of the pellicula such as plates, grooves, indentations and protuberances. This preliminary research indicates considerable potential for application of the scanning electron microscopy to study not only algal taxonomy but also the effects of contaminants in environmental surveillance.

1979 - with MUNAWAR, I.F. A preliminary account of Lake Huron phytoplankton, April to December, 1971. Can.Dept.Fish.Environm., Fish.Mar.Serv., Techn.Rept., (917).

Phytoplankton samples were collected using an integrating water sampler, at approximately four-week intervals from April to December, 1971, from 21 stations distributed over the entire Lake Huron. The Utermöhl technique was used for the first time for the identification and enumeration of all taxonomic groups of phytoplankton on a lakewide basis. The inshore stations (excluding Saginaw Bay station) showed relatively higher biomass concentration than the offshore stations. The inshore stations indicated a mean biomass ranging from 0.6 to 1.73 g/m^3 as compared to offshore or open lake stations which showed a range between 0.43 and 0.95 g/m^3. The highest mean concentration of biomass (>7.0 g/m^3) was observed at the Saginaw Bay station.

The offshore areas harboured oligotrophic flora reflecting its high water quality. On the other hand, some of the inshore areas, particularly Saginaw Bay and the vicinity, indicated extremely eutrophic conditions.

MUNAWAR, M.(cont.)

1979 - with MUNAWAR, I.F. The phytoplankton of Georgian Bay and North Channel, 1974: a preliminary study. Can.Dept.Fish.Oceans, Fish.Mar.Serv., Techn. Rept., (918).

Phytoplankton collections were made approximately at monthly intervals from 16 stations distributed across the Bay by an integrating sampler during seven cruises conducted between April and November, 1974. Similarly, samples were collected at eight stations across the North Channel during five cruises conducted between May and October, 1974. The taxonomic identification and enumeration was done by the Utermöhl technique. Based on physical characteristics, Georgian Bay and the North Channel were divided into zones in which biomass and species composition were studied.

On the average, in Georgian Bay, low biomass concentration was observed in the western and midlake portions of the Bay whereas moderate concentration was recorded in the southern, eastern, and northern zones. Highest biomass values were observed in Zone 6 off the Hope and Christian Islands. Diatoms, chrysomonads and blue-greens were the main contributors. In general, the flora of Georgian Bay is an oligotrophic type with the exception of some areas which show signs of environmental stress.

In the North Channel, lowest concentration of biomass was observed in the western portion with an increasing gradient from west to east. Diatoms, chrysomonads and cryptomonads dominated the biomass. North Channel phytoplankton assemblage in general appear to be oligotrophic except the eastern portion which showed effects of perturbation since it harboured species often associated with eutrophication.

The phytoplankton biomass and its species composition on a lakewide basis are presented for Georgian Bay and the North Channel for the first time.

1980 - Proceedings of the first Biological Surveillance Symposium, Twenty Second Conference on Great Lakes Research, May 3, 1979, Rochester, New York. (Convenor). Can.Techn.Rept.Fish.Aquat.Sci., (976).

The biological surveillance symposium in the St.Lawrence Great Lakes was conducted for the first time during the 22nd Great Lakes Research Conference (Rochester, New York, 1979). The symposium was organized to assess the state of the art in biological surveillance and consisted of 16 presentations. These proceedings are based on 9 papers, 4 extended and 3 abstracts. The symposium focussed on two major aspects of surveillance, namely 1) trophic status and 2) contaminants. It covered topics ranging from needs/objectives of biological surveillance, standardization of various techniques, importance of 'indicator species' in surveillance to integration of human health-related data into surveillance programs. The proceedings present the current status of biological surveillance in the Great Lakes.

1980 - with BISTRICKI, T. Morphological characteristics of rare ultraplankton from Lake Superior by scanning electron microscopy. Proc.Microscop.Soc.Can., 7:53-54.

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As a part of a continuing programme to study the algae of the St.Lawrence Creat Lakes, certain rare ultraplankton were observed which necessitated the use of a scanning electron microscope to investigate their micromorphology. They exhibited unusual morphological features not detectable by the standard light microscopy techniques used in algal taxonomy. Species described in this work do not conform with the available taxonomic information. It was apparent that those organisms were considerably smaller than morphological identical species reported in the literature.

1980 - with MUNAWAR, I.F. The importance of using standard techniques in the surveillance of phytoplankton indicator species for the establishment of long range trends in the Great Lakes: a preliminary example, Lake Erie. Can.Techn.Rept.Fish.Aquat.Sci., (976):59-86.

Phytoplankton analyses in the Great Lakes date back at least to the end of the past century. However, the massive data base is not comparable to the current studies in order to evaluate long-term changes of species composition associated with water quality conditions. This is mainly attributable to the diversity of methodology followed by various analysts, including data processing, reporting, and lack of sufficient taxonomic training. In spite of extensive work being carried out in the Great Lakes, no attempt has been made even today to standardize identification, enumeration, and reporting procedures. The Great Lakes Biolimnology Laboratory has collected extensive species composition data during the past 12 years. The significance and future potential of such a data base is emphasized. Floristic changes in Lake Erie are discussed to demonstrate the benefits of standardization. Our data clearly demonstrates the necessity and urgency of applying 'standard procedures' in the Great Lakes and conducting 'taxonomic workshops or courses' to provide training opportunities. Such a standard approach by all agencies involved will not only generate consistent and reliable long range data but will guarantee the availability of trained personnel for the future.

1980 - GLADISH, D.W., & MUNAWAR, M.. The phytoplankton biomass and species composition at two stations in western Lake Erie, 1975/76. Internat.Rev.ges.Hydrobiol., 65(5):691-708.

Integrated phytoplankton samples from two stations in the northern waters of western Lake Erie were analyzed by the Utermöhl technique for the period from June, 1975 to September, 1976, with weekly sampling in the summer of 1975. No consistent differences were observed between the two stations. Two annual peaks were found: the first was a vernal pulse (1.4 to 4.8 g/m^3) comprised primarily of diatoms (86.0 - 95.7 percent of total biomass; principal species were Tabellaria fenestrata (Lyngb.) Kg., Stephanodiscus hantzschii Grun., and Fragilaria capucina Desm.): the second peak (3.1 to 9.9 g/m^3) was in late summer-early fall. This latter peak consisted of initially diatoms (Coscinodiscus rothii Ehr.Grun. and Melosira granulata (Ehr.) Ralfs being the chief components), later dominated by blue-greens Aphanizomenon flos-aquae (L.) Ralfs and Chroococcus minutus (Keutz.) Naegeli), and finally diatoms (Coscinodiscus

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rothii, *Stephanodiscus* spp., *Fragilaria crotonensis* (Edw.) Kitton, and *Melosira granulata*). The importance of phytoflagellates (25.5 to 93.4 percent of total biomass), especially *Gymnodinium* sp., *Cryptomonas erosa* Ehrb., and *Cryptomonas erosa* var. *reflexa* Marsson., in June-early July samples and the overwhelming dominance of diatoms during the remainder of the yOar are stressed. No patterns in biomass and composition could be observed in vertical phytoplankton profiles. The present study provides an important connecting link between past and future studies performed with the standard Utermöhl technique.

1981 - with MUNAWAR, I.F. A general comparison of the taxonomic composition and size analyses of the phytoplankton of the North American Great Lakes. Verh.Internat.Verein.Limnol., *21*:1695-1716.

A general overview of the North American Great Lakes phytoplankton has been presented for the first time based on extensive data base collected during the past 10 years. Mean phytoplankton biomass distribution on a lakewide basis reflected more or less the water quality conditions across the Great Lakes, with Lake Superior being the most oligotrophic and Lake Erie being eutrophic in nature. Lower Great Lakes exhibited a distinct inshore/offshore developmental pattern which was not obvious in the Upper Great Lakes.

Diatomeae was the dominant taxonomic group in all the lakes studied, but the overwhelming contribution of phytoflagellates (Cryptophyceae, Chrysophyceae, Dinophyceae) was apparent. Species composition revealed an interesting comparison of Great Lakes ranging from oligotrophy to eutrophy. Species characteristic of oligotrophic environments were dominant in Lake Superior, North Channel, Georgian Bay and Lake Huron with the exception of certain local and inshore regions. Species usually associated with eutrophication were common in Lake Erie (particularly in the western basin), Lake Ontario (inshore region), Saginaw Bay and other inshore areas.

Several rare species mostly belonging to phytoflagellates were reported for the first time in the Upper Lakes, particularly in Lake Superior. Lake Ontario harboured considerable numbers of 'colourless' forms, suggesting a more complex ecosystem deserving further investigation.

Size analyses of phytoplankton biomass indicated that nannoplankton dominated the community. Fractionation of chlorophyll *a*, carbon-14 and grazing experiments with various size fractions of algae confirmed the overwhelming importance of nannoplankton in the Great Lakes limnology with micro-algae and ultraplankton playing a key role.

Our phycological research of over one decade has generated for the first time a sound and consistent database for long-term trend evaluations and also for future inter-lake comparisons which is part of the continuing Canadian effort to preserve the water quality of the Great Lakes. Our data strongly supports the necessity of continuing this phycological research on a regular basis by standard techniques and data handling procedures. It also emphasizes the need for continued maintenance of such a data base, including a reference

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collection of samples and relevant taxonomic material, to facilitate a better understanding of the past, present, and future of a complex ecosystem.

1981 - VERDUIN, J., & MUNAWAR, M. Estimates of open water photosynthesis in the North American Great Lakes. Verh.Internat.Verein.Limnol., 21:1717-1724.

Clear and dark bottle data, when compared with open water data, yield estimates of gross photosynthesis that are too low by a factor of two. Consequently, it is postulated that the actual yield per mg of chlorophyll a (0.33 mmol hr^{-1} at optimal light, from bottle data) is about 0.66, and that the average for the euphotic zone is 0.4 mmol mg^{-1} hr^{-1}. It is further postulated that this value represents a valid mean over the spectrum of lake nutrient conditions (nutrient-poor to nutrient-rich).

A simple equation for predicting summer mean daily gross photosynthetic yields is derived:-

$$\underset{(\text{mmol m}^{-2}\text{day}^{-1})}{\text{Gross PS}} = 0.4 \text{ X } \underset{(\text{mg m}^{-3})}{\text{chl } \underline{a}} \text{ X } \underset{(\text{m})}{\text{EZ}} \text{ X } \underset{(\text{hr})}{\text{day length}}$$

This equation, when applied to the North American Great Lakes predicts mean summer gross photosynthetic yields of about 200 mmol m^{-2}day^{-1}. Only for the western basin of Lake Erie a two-fold higher yield is predicted.

Using Canada Centre for Inland Waters data (O_2-depth and pH-depth profiles) the 'community net' photosynthetic yields in open offshore waters were computed for Lakes Superior, Huron and Ontario. These computations confirm the high yields predicted by the above equation and indicate that low photosynthetic yields per unit chlorophyll a routinely encountered when using ^{14}C-based methods do not reflect the true productivity of lakes.

1981 - ROSS, P.E., & MUNAWAR, M. Preference for nannoplankton size fractions in Lake Ontario zooplankton grazing. J.Great Lakes Res., 7(1) :65-67.

In *in situ* zooplankton grazing experiments in Burlington Canal, smaller nannoplankton (1-20 µm) were greatly preferred over the larger (20-64 µm) fraction. The majority (94.4 percent) of the cells ingested by the rotifer *Kellicottia longispina* were from the smaller fraction. Similarly, the 1-20 m fraction accounted for 91.9 percent of the cells ingested by the cladoceran *Bosmina longirostris* and 94.8 percent of those ingested by mixed copepod nauplii. The rotifer feeding rates were slower than those of the crustacean zooplankton studied. The results imply that contaminant transfer pathway studies should focus on smaller algae as being crucial in phytoplankton-zooplankton links in trophic models.

1982 - Toxicity studies on natural phytoplankton assemblages by means of fractionation bioassays. Can.Techn.Rept.Fish.Aquat.Sci., (1152).

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The toxicity experiments were carried out in the Great Lakes during spring, summer and fall of 1979, 1980 and 1981. Algal fractionation approach was applied in the toxicity studies for the first time using natural phytoplankton assemblage. By means of carbon-14 uptake fractionation, differential response of various size fractions, such as <10, 10 to 20, 20 to 64, and >64 µm, to various concentrations of a metal mixture was assessed. These results suggest that the nannoplankton and particularly the smaller size fraction, <10 µm, was much more susceptible to inhibition by the mixture of heavy metals. Since it is also this group of algae that is preferred by herbivorous zooplankton, these results have strong implications for contaminant pathway management.

1982 - with FAHNENSTIEL, G.L. The abundance and significance of ultraplankton and micro-algae at an offshore station in central Lake Superior. Can.Techn.Rept.Fish.Aquat.Sci., (1153).

Determinations of chlorophyll a and in situ carbon-14 uptake were made on fractionated water samples from three depths at an offshore station in central Lake Superior each month from May to October, 1979. The mean chlorophyll a concentration data indicated that 91 percent of the pigment was found in the nannoplankton (<64 µm), and only 9 percent in the netplankton (>64 µm). The µ-algae or picoplankton (<3 µm) and ultraplankton (5 to 20 µm) components of the nannoplankton contained concentrations of chlorophyll a of 42 and 25 percent of the pigment respectively. Similarly, a mean carbon-14 uptake value of 93 percent was found in the nannoplankton. The µ-algae and ultraplankton components were the most active of the phytoplankton assemblage, being responsible for 47 and 24 percent of the carbon-14 uptake respectively. This dominance of minute organisms in the Lake Superior phytoplankton community metabolism is unique and suggests the need for further experimental research on the physiological basis of their active existence.

1982 - with MUNAWAR, I.F. Phycological studies in lakes Ontario, Erie, Huron, and Superior. Can.J.Bot., 60(9):1837-1858.

An indepth phycological comparison is presented for lakes Ontario, Erie, Huron, and Superior, based on extensive lake-wide surveys carried out during the past 12 years. This comparison was achieved by the application of standard and consistent identification, enumeration, and data-processing techniques. The resulting species composition data are voluminous and present a broad picture of the phytoplankton assemblage. Our data base has enabled us to assess the long-term floristic changes, knowledge of which is lacking in the Great Lakes. The species composition reflects more or less the current trophic status of these lakes. The preponderance of nannoplankton and phytoflagellates is the subject of our current experimental research, which includes the fractionation of chlorophyll a and carbon-14 uptake, toxicity studies of heavy metals upon various size fractions of algae, and the role of microalgae and ultraplankton in the transfer of contaminants via zooplankton grazing. The need for phycological research in the Great Lakes is expanding with decreasing eutrophication and the increasing problems

MUNAWAR, M.(cont.)

of contaminants. The recovery, rehabilitation, and preservation of these vital freshwaters are the primary concern of the continuing Canadian research program in the Great Lakes.

1982 - with MUNAWAR, I.F., ROSS, P.E., & DAGENAIS, A. Microscopic evidence of phytoplankton passing through glass-fibre filters and its implications for chlorophyll analysis. Arch.Hydrobiol., 94(4):520-528.

Water samples from Lake Ontario were filtered through Whatman GF/C glass-fibre filters (1.2 μm) as per the routine chlorophyll procedure of STRICKLAND & PARSONS. The resulting filtrate was then preserved with Lugol's solution and enumerated by the Utermöhl technique. A mean of 40 taxa from 6 algal classes were found in the filtrate out of 68 phytoplankton taxa in an unfiltered reference sample. Compared to the reference sample, 25 percent of the cell numbers passed through the filter, but only 1.3 percent of the biomass, as the escaping cells were mostly small ones. Separate experiments on parallel chlorophyll determinations showed that 0.2 μm nuclepore and 0.45 μm cellulose membranes retained more chlorophyll than glass-fibre filters. Error due to cells passing through filters is suggested as one of the reasons why published phosphorus-chlorophyll relationships are so variable. This type of error would be most serious in oligotrophic waters, where small cells form a large proportion of the total biomass.

1982 - BISTRICKI, T., & MUNAWAR, M. Application of X-ray microanalysis for the detection of heavy metals in Great Lakes algae. Can.J. Fish.Aquat.Sci., 39:506-509.

A combination of scanning electron microscopy and energy dispersive X-ray spectroscopy (SEM-EDX) was found to be a very effective tool for characterizing the heavy metal load of Great Lakes phytoflagellates, diatoms, and green algae, and for the surveillance of heavy metal pollution. The sensitivity and short generation time of nannoplankton and the speed of the described technique makes this procedure a useful aid in contaminants research.

1983 - with MUDROCH, A., MUNAWAR, I.F., & THOMAS, R.L. The impact of sediment-associated contaminants from the Niagara River mouth on various size assemblages of phytoplankton. J.Great Lakes Res., 9(2) :303-313.

The impact of elutriated sediment-associated contaminants from the Niagara River mouth and from a midlake station in Lake Ontario on various size assemblages of natural phytoplankton was determined. The C^{14} fractionation bioassays indicated that the addition of Chelex-treated elutriate (without dissolved metals) from the Niagara River mouth enhanced the C^{14} uptake when compared to the standard elutriate. Conversely, at the midlake station, the addition of standard elutriate (with dissolved metals) induced higher C^{14} uptake than the Chelex-treated elutriate. It is apparent that the synergistic effects of nutrients/metals and metals/organic compounds determine the bioavailability and toxicity of contaminants to

MUNAWAR, M. (cont.)

natural phytoplankton. Our technique is sensitive and useful in detecting the differential response of algal size fractions to contaminants.

1983 - MAYFIELD, C.I., & MUNAWAR, M. Preliminary study of the effects of contaminants from sediments on algal membranes. J.Great Lakes Res., 9(2):314-316.

Fluorescence depolarization is used to examine the effects of contaminants on the microviscosity of cell membranes of Ankistrodesmus sp. cells. One mg/L additions of Hg and Cd to the alga caused a change in the measured 'index of viscocity' of the Ankistrodesmus cells in comparison to the index obtained by the addition of Zn and Pb. Elutriates from contaminated Niagara River sediment samples also caused an increase in the 'index of viscosity', whereas elutriate from uncontaminated sediments from the mid-lake station of Lake Ontario had no effect. This method has the potential for application in the assessment of the effects of contaminants on algal populations.

1984 - with THOMAS, R.L., SHEAR, H., McKEE, P., & MUDROCH, A. An overview of sediment-associated contaminants and their bioassessment. Can. Techn.Rept.Fish.Aquat.Sci., (1253).

An overview of the published material concerning sediment contamination by trace metals and persistent organics is presented. Information from the Great Lakes is highlighted. Physico-chemical processes governing the behaviour of contaminants in sediments are discussed. The impact of sediment contamination on aquatic biota as well as effect of biota on contaminants are considered. Approaches and procedures used to determine the bioavailability and bioassessment of sediment-associated contaminants are outlined.

1985 - The delivery and bioavailability of particulate bound phosphorus in Canadian rivers tributary to the Great Lakes. See under THOMAS, R.L.

1985 - with THOMAS, R.L., NORWOOD, W., & MUDROCH, A. Toxicity of Detroit River sediment-bound contaminants to ultraplankton. J.Great Lakes Res., 11(3):264-274.

Four sites in the Detroit River/Lake Erie western basin were evaluated for their toxicity. The evaluation was based on 1) bulk chemical characterization of the sediments, 2) chemical composition of the sediment elutriates, and 3) toxicity of the elutriates to ultraplankton and microplankton/net plankton. A sequence of decreasing contamination was determined from the chemical composition of the elutriates based on the elutriation release of metals such as Zn, Mn, Cd, Ni, and Co. Bioassessment of elutriate toxicity was determined by carbon-14 Algal Fractionation Bioassays (AFB's) which were conducted with various dilutions of standard and Chelex-100 treated elutriates. Site A (near Windsor, Ontario) and site D (western Lake Erie) were found to be toxic to ultraplankton. The observed toxicity was attributed to the bioavailability and synergistic impact of elutriated metals on ultra-plankton production. A direct relationship between the water soluble metal fraction and toxicity was observed. These results confirmed that sediment toxicity should not be evaluated solely on bulk chemical composition of the sediments. The AFB's have been proven useful in the bioassessment of sediments due to their rapidity/sensitivity and hence could be routinely used for the screening and early detection of contaminants affecting fast growing organisms which form the basis of the aquatic food chain.

1986 - with THOMAS, R.L., NORWOOD, W.P., & DANIELS, S.A. Sediment toxicity and production-biomass relationships of size-fractionated phytoplankton during on-site simulated dredging experiments in a contaminated pond. In; P.G.SLY(ed.), Sediments and Water Interactions:407-426. Springer-Verlag. ISBN 0-387-96293-X.

This project was conducted as a pilot study; it simulated dredging and disposal processes and examined the impact of sediment-bound contaminants on phytoplankton in a contaminated pond. The investigation attempted to explore both complex sediment-water interactions and the effects of resulting toxicity under natural conditions. ^{14}C algal fractionation bioassays (AFB's) with natural phytoplankton populations were utilized for toxicity testing. Incubations were performed with a thermostatically controlled, constant light incubator taken to the site in a mobile laboratory. The impact of sediment-associated contaminants was determined on two algal size fractions; namely ultraplankton (<20 µm) and microplankton/net plankton (>20 µm). The results indicated both inhibition (toxicity) and enhancement (nutrient enrichment) of the relative assimilation activity or production/biomass quotients (mg C_{ass} mg^{-1} $Chl.h^{-1}$) by both size assemblages. These results were attributed to the synergistics interactions of nutrients and metals originating from the simulated dredgings.

The bioassays performed with fractionated natural phytoplankton were rapid and sensitive, and provide an inexpensive means of evaluating the impact of dredging and disposal activities on the productivity of aquatic ecosystems. The study demonstrated the potential of the technique for monitoring and management of dredging and disposal perturbations in harbors and offshore areas. The application of EC-50 values based on the bioassay data could serve as a promising on-site bioassessment tool for developing dredging and disposal guidelines, and for management of in-place pollutants from a regulatory point of view.

1986 - SPRULES, W.G., & MUNAWAR, M. Plankton size spectra in relation to ecosystem productivity, size, and perturbation. Can.J.Fish. Aquat.Sci., 43:1789-1794.

Quantification and comparisons of the structure of open-water plankton communities from 25 inland lakes of Ontario, from the Laurentian Great Lakes Superior, Huron, St.Clair, Ontario, and Erie, and from the Central Gyre in the North Pacific Ocean were made on the basis of the normalized biomass size spectrum. Residual variation around the fitted straight lines (corresponding to a

MUNAWAR, M.(cont.)

theoretical steady state) was least for the large, oligotrophic Lake Superior and the North Pacific Gyre and greatest for eutrophic Saginaw Bay and shallow Lake Erie, suggesting progressive departure from steady-state conditions with increasing system productivity. The slopes of the normalized spectra decrease with increasing eutrophy, indicating that nannoplankton abundances are similar in all communities studied, but that associated zooplankton abundances vary by 2.5 orders of magnitude. Our results suggest that parameterization of particle-size models for prediction of potential fish production must be adjusted according to the size and productivity of the ecosystem and that routine monitoring of communities by the normalized biomass spectrum could provide early warning of nutrient or toxic stress in aquatic ecosystems.

1986 - with MUNAWAR, I.F. The seasonality of phytoplankton in the North American Great Lakes, a comparative synthesis. Hydrobiologia, 138:85-115.

The phytoplankton and productivity of the North American Great Lakes has been studied extensively by Fisheries and Oceans Canada during the past 15 years to monitor the impact of nutrient and contaminant loading on the plankton of the ecosystem. Lakewide cruises were conducted at monthly intervals mainly during the spring to fall period. This provided extensive biomass, species, size, productivity and nutrient concentration data for the Great Lakes. These data were collected using the Utermöhl inverted microscope technique together with standardized taxonomic, productivity and data-handling procedures. These standardized methodologies were applied to all the Great Lakes which resulted in a comprehensive phycological and ecological data base for the first time. These data form the basis for the evaluation of the complex phenomenon of seasonality.

The eutrophic/mesotrophic Lower Great Lakes exhibited well-developed seasonal peaks of high biomass, with inshore-offshore differentiation and spring maxima most pronounced in the inshore region. However, the oligotrophic Upper Great Lakes had low biomass and generally lacked well-developed seasonal patterns. No marked seasonal trends were observed in the ultra-oligotrophic Lake Superior. The seasonality of biomass and various taxonomic groups of phytoplankton showed differentiation between individual lakes and is discussed in detail. The seasonal succession of species provided interesting comparisons between the Lower Great Lakes, which harbour eutrophic and mesotrophic species, and the Upper Great Lakes, which harbour oligotrophic species.

Due to the voluminous nature of our data, a general overview has been given for all the Great Lakes with Lake Ontario treated in detail as a case study. The Lake Ontario case study provides the state-of-the-art status ranging from the lakewide surveys of 1970 to the current research with minute organisms such as ultraplankton and picoplankton.

1986 - with J.F.TALLING(Guest editors). Seasonality of freshwater phytoplankton: a global perspective. Hydrobiologia, 138.

NAUWERCK, A.

1971 - The composition and horizontal distribution of phytoplankton in Lake Ontario during the year 1970. See under MUNAWAR, M.

1973 - A comparison of electronic particle counters and inverted microscope methods for counting phytoplankton. See under LESLIE, J.K.

NICHOLSON, H.F.

1970 - The chlorophyll a content of the surface waters of Lake Ontario, June to November, 1967. Fish.Res.Bd.Can., Techn.Rept., (186).

This report presents the distribution of surface chlorophyll a as determined by a continuous flow fluorometer on 11 cruises on Lake Ontario from June 12 to November 2, 1967. The highest lake mean concentration, 20.3 mg/m^3, occured during June 12-17, followed by a rapid decline to the lowest lake mean concentration of 3.7 mg/m^3 between June 28 and July 10. Thereafter, the mean lake surface concentration varied between 3.8 and 8.4 mg/m^3.

1970 - CHAU, Y.K., CHAWLA, V.K., NICHOLSON, H.F., & VOLLENWEIDER, R.A. Distribution of trace elements and chlorophyll a in Lake Ontario. Proc.13th.Conf.Great Lakes Res.1970:659-672.

Horizontal and vertical distributions of concentrations of 12 trace elements (Cd, Cr, Co, Cu, Fe, Pb, Mn, Mo, Ni, Sr, V, and Zn) have been studied in Lake Ontario on three cruises (May, July, and September, 1969), covering 45 stations on each cruise. Attempts have been made to correlate these with the distribution of subsurface chlorophyll a.

Cadmium, cobalt and vanadium occured in extremely low concentrations and their variations were very close to the analytical errors and therefore considered insignificant. The other trace elements showed wide spatial and seasonal variations; generally high concentrations were found in the eastern and western regions of the lake, and lower concentrations occured in the central basin.

Some correlations have been observed in the subsurface distribution of chlorophyll a with zinc, with zinc + copper, with zinc + iron, and with zinc + iron + copper although these correlations were not highly significant. Generally, high chlorophyll a values in the western and eastern regions coincided with high concentrations of trace elements.

1974 - Bibliography on the limnology and fisheries of Canadian freshwaters. No.1. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (471).

This bibliography is the first of a continuing series, and contains 1,000 references and the Canadian freshwater bodies to which they refer. The intention is to collate as much as possible the available data on the limnology and fisheries of Canadian lakes and flowing waters, excluding the Great Lakes and interconnecting waters.

NICHOLSON, H.F.(cont.)

1975 - Chlorophyll a and primary production in Georgian Bay, North Channel and Lake Huron, April to December, 1974. See under WATSON, N.H.F.

1975 - Chlorophyll a and primary production in Lake Superior, May to November, 1973. See under WATSON, N.H.F.

1975 - Bibliography on the limnology and fisheries of Canadian freshwaters. No.2. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (504).

This is the second bibliography of a continuing series and contains a further 1,000 references and the freshwater features to which they refer.

1975 - Bibliography on the linnology and fisheries of Canadian freshwaters. No.3. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (566).

This is the third bibliography in a continuing series and contains a further 1,000 references and the freshwater features to which they refer. Commencing with this issue, only those freshwater features whose names and coordinates have been approved by the Canadian Permanent Committee on Geographical Names will be included in these bibliographies.

1976 - Bibliography on the limology and fisheries of Canadian freshwaters. Appendix A. Cumulative author index. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (605).

This report contains a list of papers, in alphabetical order of authors and co-authors, given in the Reference Index Sections published in the first three numbers of the series.

1976 - Bibliography on the linmology and fisheries of Canadian freshwaters. No.4. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (672).

This is the fourth bibliography in a continuing series and contains a further 1,000 references and the Canadian freshwater features to which they refer.

1978 - Bibliography on the limnology and fisheries of Canadian freshwaters. No.5. Can.Dept.Fish.Environm., Fish.Mar.Serv., Techn.Rept., (804).

This bibliography is the fifth of a continuing series and contains a further 500 references and the Canadian freshwater features to which they refer.

1979 - List of the published and presented papers by the staff of the Great Lakes Biolimnology Laboratory, 1968-1978. Can.Dept.Fish. Environm., Fish.Mar.Serv., Techn.Rept., (874).

A list of 245 papers, either published or presented, by the staff of the Great Lakes Biolimnology Laboratory from 1968 to 1978 inclusive, is given. The areas of research covered include Descriptive Biology, Ecosystems Metabolism, Environmental Toxicology, and Sedimentology.

NICHOLSON, H. F.(cont.)

Also included is a list of 127 published and presented papers by the present staff prior to their joining this laboratory.

1980 - Bibliography on the limnology and fisheries of Canadian freshwaters. No.6. Can.Dept.Fish.Environm., Fish.Mar.Serv., Techn.Rept., (911).

This is the sixth of a continuing series and contains a further 500 references and the Canadian freshwater features to which they refer.

1982 - Bibliography on the limnology and fisheries of Canadian freshwaters. No.7. Can.Dept.Fish.Oceans, Great Lakes Fish.Res.Br., Internal Rept.

1983 - Bibliography on the limnology and fisheries of Canadian freshwaters. No.8. Cumulative edition. Can.Dept.Fish.Oceans, Great Lakes Fish.Res.Br., Internal Rept.

1983 - (Editor). Great Lakes Fisheries Research Branch Annual Review, 1981. Can.Dept.Fish.Oceans, Great Lakes Fish.Res.Br.

1985 - (Editor). Great Lakes Fisheries Research Branch Annual Review, 1982. Can.Dept.Fish.Oceans, Great Lakes Fish.Res.Br.

1985 - Bibliography on the limnology and fisheries of Canadian freshwaters. No.9. Cumulative edition. Can.Dept.Fish.Oceans, Great Lakes Fish.Res.Br., Internal Rept.

1986 - (Editor). Progress report of the Great Lakes Fisheries Research Branch for 1983. Can.Techn.Rept.Fish.Aquat.Sci., (1495).

NIIMI, A.J.

1978 - Lag adjustment between estimated and actual physiological responses conducted in flow-through systems. J.Fish.Res.Bd.Can., 35:1265-1269.

The results from physiological experiments that use a flow-through or open system may be biased because of lag. The nature of this discrepancy is attributable to a delay between the actual response of an organism and the measured response of the system. An equation is presented that would adjust the measurement for lag. This procedure is especially important when measuring time-dependent uptake and depuration rates like those reported in respiratory and toxicological studies.

1979 - Proceedings of the Fifth Annual Aquatic Toxicity Workshop, November 7-9, 1978, Hamilton, Ontario. See under WONG, P.T.S.

1979 - Hexachlorobenzene (HCB) levels in Lake Ontario salmonids. Bull.Environm.Contam.Toxicol., 23:20-24.

Hexachlorobenzene (HCB) levels were monitored in lake trout (Salvelinus namaycush), rainbow trout (Salmo gairdneri) and coho salmon (Oncorhynchus kisutch) that were collected from Lake Ontario.

NIIMI, A.J.(cont.)

HCB levels in the respective species averaged 80, 62, and 36 µg kg HCB and^{-1}concentrations increased significantly ($P<0.05$) as fish weight increased.

1979 - Quantitative analysis of carbon-14 labelled polychlorinated biphenyls and hexachlorobenzene in biological samples using an oxidative combustion method. Internat.J.Environm.Analyt.Chem., 6:267-271.

Carbon-14 labelled glucose, polychlorinated biphenyls, and hexachlorobenzene at concentrations of 0.01 to 1200 nanograms were oxidized in a combustion chamber at 900°C. The $^{14}CO_2$ emitted was trapped in an organic base, and its radioactivity measured. Recovery rates of 95 to 104 percent were obtained from samples oxidized with mannitol, while recoveries of samples oxidized with dried fish ranged from 93 to 101 percent. This method provides an alternate technique of sample preparation for materials that may yield a highly quenched solution following conventional sample preparation procedures for liquid scintillation methods.

1979 - with BURNISON, G.A. Recovery of ^{14}C-labelled polychlorinated biphenyls (PCB) in fish tissue using a combustion and a solubilization method of sample preparation for scintillation analysis. Bull.Environm.Contam.Toxicol., 23:597-600.

The extraction efficiency of ^{14}C-labelled PCB from biological tissue were compared using the oxidative combustion and alkali tissue solubilizer methods. The combustion method was preferred because of lower detection limits and less variation among replicate samples.

1980 - with CHO, C.Y. Uptake of hexachlorobenzene (HCB) from feed by rainbow trout (*Salmo gairdneri*), Bull.Environm.Contam.Toxicol., 24:834-839.

Rainbow trout, averaging 150 g each, were fed diets containing 4, 6, 8, 394, and 780 µg kg^{-1} HCB daily for up to 57 days. Residue levels in fish fed the three lower concentrations averaged 4 to 8 µg kg^{-1} HCB at the end of the study. Those fed the 394 µg kg^{-1} diet averaged 200 µg kg^{-1} HCB, while those fed the highest dose averaged 635 µg kg^{-1} HCB. It was estimated that 80 percent of the HCB that was ingested was retained by the fish. The results of this and related studies would suggest that food would represent an important pathway for HCB accumulation by fish.

1980 - with MORGAN, S.L. Morphometric examination of the gills of walley *Stizostedion vitreum Vitreum* (Mitchill) and rainbow trout, *Salmo gairdneri* Richardson. J.Fish Biol., 16:685-692.

Observations on the gill morphology of individual gill arches of walleye and rainbow trout suggest that the first two arches account for the highest proportion of gill filament number, secondary lamellae number, lamellae area, and gill surface area. Interspecific comparisons suggest walleye contain a larger number of gill

NIIMI, A.J.(cont.)

filaments, with a lower secondary lamellae count, but a larger gill surface area than a trout of the same weight. This is partially attributed to the larger surface area of each lamella in a walleye than in a trout.

A detailed examination suggests the surface area of a lamella is dependent on its position on the gill filament, and the position of the gill filament on the gill arch.

1981 - Gross growth efficiency of fish (K_1) based on field observations of annual growth and kinetics of persistent environmental contaminants. Can.J.Fish.Aquat.Sci., **38**:250-253.

The gross growth efficiency of fish (K_1) in the field was estimated by incorporating concepts from fish physiology and environmental toxicology into a growth model. Using lake trout and coho salmon as examples, annual growth was estimated from age vs weight relationships, and food intake was estimated from annual increases in body burden of polychlorinated biphenyls (PCB) Log K_1 is suggested to decrease over the life span of a fish.

1981 - with CHO, C.Y. Elimination of hexachlorobenzene (HCB) by rainbow trout (*Salmo gairdneri*) and an examination of its kinetics in Lake Ontario salmonids. Can.J.Fish.Aquat.Sci., **38**:1350-1356.

Subadult rainbow trout were fed diets containing hexachlorobenzene (HCB) to establish mean body burdens of 225 and 440 μg HCB per fish. They were sampled after 0, 24, 55, and 110 d to estimate the rate of elimination. The biological half-life or $T_{\frac{1}{2}}$ of HCB for trout under the prescribed laboratory conditions was estimated to be at least 7 mo, and perhaps as long as several years. $T_{\frac{1}{2}}$ was calculated using body burden or μg HCB per fish, and tissue concentrations or μg/kg HCB. Estimates of $T_{\frac{1}{2}}$ derived from tissue concentrations ranged from 61 to 117 d, but this was shown to be due to a relative increase in body weight over the study period. The implications of increasing body weight on kinetics measurements are discussed, and an equation is presented that adjusts for changes in body weight where estimates of $T_{\frac{1}{2}}$ are calculated using tissue concentrations.

The results of this and other studies on HCB were used to examine the kinetics of HCB in salmonids collected from Lake Ontario. Using the information derived from laboratory studies on rainbow trout, good agreement was achieved between the expected level and that monitored in field samples of rainbow trout, but only a fair agreement was suggested for lake trout (*Salvelinus namaycush*) and coho salmon (*Oncorhynchus kisutch*). Differences in the HCB kinetics of these species may be attributed to body weight, age, and perhaps feeding habits. Concentrations of HCB reported in field sampling programs generally range from 1 to 100 μg/kg in fish, and it is suggested that these levels are primarily due to the limited availability of HCB in the Lake Ontario environment.

1982 - Economic and environmental issues of the proposed extension of the winter navigation season and improvements on the Great Lakes-St. Lawrence Seaway system. J.Great Lakes Res., **8**(3):532-549.

NIIMI A.J.(cont.)

The governments of the United States and Canada must decide in the near future if vessel and cargo transit on the Great Lakes-St.Lawrence Seaway (GL-SLS) is to be operated at capacity or the system be improved to accommodate the projected increases. Portions of the GL-SLS could approach operating capacity in the mid-1980's and options to increase capacity include extending the present 8.5 month navigation season to 11-12 months, and/or upgrading existing facilities to accommodate larger vessels. The U.S. Army Corps of Engineers is one of the few groups which has examined this issue in depth, and has concluded that it is technically and economically feasible to increase the capacity.

The economic and environmental issues of the Corps proposal are discussed as viewed from a Canadian perspective. Total cost of the proposed improvements is difficult to establish because some economic costs and benefits can be identified while others are less obvious, and environmental costs and benefits have not been adequately assessed to provide the basis for a rational judgement. The major economic and environmental concerns are discussed to demonstrate the need for more information that would be required by both countries to make an equitable decision.

An evaluation of the proposed improvements to the GL-SLS on the environmental resources of Canada is presented. Environmentally sensitive areas such as shorelines, wetlands, and inshore and shallow areas along the interconnecting waterways have been characterized and it is evident that a large percentage of these areas occur within Canadian waters. Furthermore, most of the major capital improvements proposed for the system are in Canada. In view of this, it is suggested that the cost-sharing arrangement between the U.S. and Canada proposed by the Corps of Engineers for improvements on the GL-SLS would not be in the best interest of Canada.

1982 - with McFADDEN, C.A. Uptake of sodium pentachlorophenate (NaPCP) from water by rainbow trout (Salmo gairdneri) exposed to concentrations in the ng/L range. Bull.Environm.Contam.Toxicol., 28:11-19.

The toxicological implications on the accumulation of PCP from prolonged exposure to fish can only be surmised from the information that is available. Exposure to sublethal concentrations of 100 μg/L for prolonged periods may induce cytological changes in the liver. LC_{50} studies indicate PCP can be lethal at 40-600 μg/L and growth is impaired by prolonged exposure to concentrations of less than 10 μg/L, but studies of this nature generally do not measure PCP levels in the fish. Measurements on fish surviving in heavily contaminated waters indicate tissue levels of approximately 700 μg.kg PCP is not acutely toxic. Results from acute toxicity studies on goldfish suggest mortality occurs when PCP concentrations in tissues approach 100 mg/kg. In view of these observations and the results of this study, it is suggested that chronic exposure of rainbow trout to waterborne NaPCP at concentrations up to 660 ng/L would not likely to be lethal with prolonged exposure, but adverse effects at the sublethal level particularly among young fish is probable.

NIIMI A.J.(cont.)

1983 - OLIVER, B.G., & NIIMI, A.J. Bioconcentration of chlorobenzenes from water by rainbow trout: correlations with partition coefficients and environmental residues. Environm.Sci.Technol., 17:287-291.

The bioconcentration by rainbow trout of ten chlorobenzenes (CB's), hexachlorobutadiene (HCBD), and hexachloroethane (HCE) at water concentrations near environmental levels (nanograms per liter range) has been studied. The bioconcentration factor (BCF) for the CB's was found to increase dramatically as the degree of chlorine substitution on the aromatic ring became greater. There was a high correlation between the BCF and the octanol-water partition coefficient for HCBD, HCE, and all the chlorobenzenes except hexachlorobenzene (HCB). Ten adult rainbow trout from Lake Ontario were analyzed for these contaminants. Then, with use of field values for contaminant concentrations in water and laboratory values for BCF's, predictions of field concentrations in fish (on the basis of accumulation from water only) were made. These values were then compared to the fish field data.

1983 - LOWE-JINDE, L., & NIIMI, A.J. Influence of sampling on the interpretation of haematological measurements of rainbow trout, Salmo gairdneri. Can.J.Zool., 61(2):396-402.

Haematological parameters of rainbow trout were examined to determine if the sampling influenced the measurements. The results indicated that haematocrit values of fish anesthetized with tricaine methanesulfonate (TMS or MS 222) sampled after 5-20 min were significantly higher than of fish sampled within 1 min of capture and anesthesia. No differences were observed among haemoglobin content, erythrocyte, and leucocyte counts of their differential cell ratios over the 20-min period. Haemoglobin content and erythrocyte counts increased significantly with size among the three groups examined. It is suggested that differential blood cell ratios could be used as a reliable haematological index because the ratios appear to be independent of the effects of sampling over a short time period.

1983 - LOWE-JINDE, L., & NIIMI, A.J. Is Trypanoplasma salmositica present in Lake Ontario salmonids? J.Great Lakes Res., 9(4):588-589.

During the period June-October 1981, fish, including lake trout (Salvelinus namaycush), brown trout (Salmo trutta), rainbow trout (Salmo gairdneri) and coho salmon (Oncorhynchus kisutch), were collected from four locations on Lake Ontario. In addition, juvenile coho salmon reared from Lake Ontario fish eggs and maintained in a hatchery were collected. Subsequently, air-dried blood smears were stained with Leishman-Giesma and examined under oil emersion for Trypanoplasma salmositica. In this study of 131 fish, no T.salmositica were found. From these findings it may be assumed that T.salmositica are either rare or not present in Lake Ontario salmonids.

NIIMI, A.J. (cont.)

1983 - Biological and toxicological effects of environmental contaminants in fish and their eggs. Can.J.Fish.Aquat.Sci., 40:306-312.

Rainbow trout (Salmo gairdneri), white sucker (Catostomus commersoni), white bass (Morone chrysops) smallmouth bass (Micropterus dolomieui), and yellow perch (Perca flavescens) were collected from Lakes Ontario and Erie to examine the relationship between contaminant levels in females and their eggs. Factors such as the percent lipid in the fish and percent of total lipid deposited in the eggs significantly influenced ($P < 0.01$) contaminant transfer. The percentages of the 9-11 organic contaminants transferred generally showed less variation within a species than the percentages for a substance transferred among the five species examined. This relationship was consistent even though there was over a 10-fold range in contaminant concentrations within a given species. Mercury did not demonstrate this response because the percentage in eggs was low for all species. The levels of PCB monitored in eggs of rainbow trout collected from Lake Ontario suggest that egg and fry survival rates could be affected based on the toxicological evidence from other studies. An examination of the possible effects of spawning on the kinetics of contaminants among these species suggests that relative body concentrations of organic contaminants may be decreased by 5 percent or be increased by 10 percent, and mercury levels may be increased by 6-22 percent following the deposition of eggs. The amount of change varies with species and is influenced by the percent egg weight of body weight, and the rate of contaminant transfer from females to eggs.

1983 - Physiological effects of contaminant dynamics on fish. In; J.O.NRIAGU(ed.), Aquatic Toxicology:207-246. John Wiley & Sons. ISBN 0-471-88901-6.

1983 - with CHO, C.Y. Laboratory and field analysis of pentachlorophenol (PCP) accumulation by salmonids. Wat.Res., 17(12):1791-1795.

Rainbow trout were fed diets containing 10-3,000 $\mu g\ kg^{-1}$ pentachlorophenol (PCP) for up to 110 days to examine its accumulation. Fish fed the 10 $\mu g\ kg^{-1}$ diet maintained whole body levels of 2 $\mu g\ kg^{-1}$ PCP over the study period, while PCP levels in those fed the 3,000 $\mu g\ kg^{-1}$ diet increased to 40 $\mu g\ kg^{-1}$ after 40 days, then decreased thereafter to 20 $\mu g\ kg^{-1}$ at the end of the study. The biological half-life ($T_{\frac{1}{2}}$) Of PCP in trout was estimated to be approx. 7 days. PCP levels in six species of fish representing two trophic levels from Lake Ontario were also monitored, most species contained 1-10 $\mu g\ kg^{-1}$ PCP. The results of these and other studies would suggest PCP accumulation in fish is primarily through direct uptake from water rather than accumulation through the food-chain.

1983 - with OLIVER, B.G. Biological half-lives of polychlorinated biphenyl (PCB) congeners in whole fish and muscle of rainbow trout (Salmo gairdneri). Can.J.Fish.Aquat.Sci., 40:1388-1394.

NIIMI, A.J. (cont.)

The biological half-life ($T_{\frac{1}{2}}$) of 31 dichloro- to decachloro-biphenyl congeners were monitored for 105 d in adult rainbow trout that were exposed to a single oral dose. In whole fish $T_{\frac{1}{2}}$ increased from 5 d to no apparent elimination as the number of chlorines on the biphenyl increased. The structure-activity relationship was not as evident in muscle where $T_{\frac{1}{2}}$ ranged from <5 to 127 d. We suggest the decline in muscle resulted from decreasing lipid levels and the redistribution of congeners within the fish. From structure-activity analysis of $T_{\frac{1}{2}}$ in whole fish we conclude that elimination is enhanced for those congeners with lower chlorine content, with no chlorine substitutions in the ortho positions, and those with two unsubstituted carbons that are adjacent (vicinal) on the biphenyl. A significant decline in total PCB content in whole fish, equivalent to a $T_{\frac{1}{2}}$ of 219 d, was partly due to the composition of the PCB mixture administered, and the selective elimination of the lower chlorinated biphenyls.

1984 - OLIVER, B.G., & NIIMI, A.J. Rainbow trout bioconcentration of some halogenated aromatics from water at environmental concentrations. Environm.Toxicol.Chen., 3:271-277.

The bioconcentration of 10 brominated and chlorinated aromatics by rainbow trout at ng/L concentrations, approaching environmental levels, has been studied. Seven of the compounds (3,4-dichlorobenzotrifluoride; 2,4,5-trichlorotoluene; 2,3,4-trichloroanisole; 1,4-dichloronaphthalene; 1,3-dibromobenzene; 1,3,5-tribromobenzene; 1,2,4-tribromobenzene) reached a steady equilibrium concentration in the fish over the 90 day study period. Fish residue levels for the other 3 compounds (2,4-dichlorodiphenyl-ether; 1,2,4,5-tetrabromobenzene; 4,4'-dichlorobiphenyl) continued to increase over the entire study period. A good linear correlation ($r^2=0.79$) between log bioconcentration factor (BCF) and log octanol-water partition coefficient (K) was found for the seven equilibrated compounds with a slope of 0.99. A good correlation between log BCF and parachor was also found for selected chemicals from this and an earlier study. Compounds that did not equilibrate plotted well below the log BCF versus log K line and had K values of $>10^5$ and parachors (surface tension corrected molar volumes) >400.

1984 - with LOWE-JINDE, L. Differential blood cell ratios of rainbow trout (*Salmo gairdneri*) exposed to methylmercury and chlorobenzenes. Arch.Environm.Contam.Toxicol., 13:303-311.

The differential red and white blood cell ratios were examined in subadult rainbow trout that were exposed to low level concentrations of waterborne methylmercury and chlorobenze. The results indicated little or no changes among the ratios even though fish were exposed for 75 to 119 days and accumulated residue levels of 3 to 12 mg/kg.

Blood cell ratios were also examined in rainbow trout collected from Lake Ontario. These ratios were different from those observed in the laboratory studies, particularly among the leucocytes where the lymphocytes, thrombocytes, and granulocytes averaged 83-90, 4-14, and 2-3 percent among the laboratory fish, and 37, 48, and 15

NIIMI, A.J. (cont.)

percent in Lake Ontario fish respectively. The feasibility of using differential blood cell ratios as a physiological indicator of contaminant stress is discussed.

1984 - LOWE-JINDE, L., & NIIMI, A.J. Short-term and long-term effects of cadmium in glycogen reserves and liver size in rainbow trout (Salmo gairdneri Richardson). Arch.Environm.Contam.Toxicol., 13:759-764.

Salmo gairdneri Richardson were exposed to three test concentrations of 36, 12 and 4 µg Cd/L for varying exposure periods of 1-84 days; blood glucose and lactate, liver and muscle glycogen and liver size were examined. The highest cadmium concentration produced marked depletion of glycogen content of both liver and muscle. This response was evident after 1 day post cadmium exposure and persisted on the subsequent second and third day exposure but not on 42 day exposure. Tissue glycogen levels were maintained within control values at lower cadmium concentrations. The liver size increased in the lowest cadmium concentrations (4 µg/L) after days 56 and 84. The mobilization of certain energy reserves to meet the stress of high cadmium exposure and the enlargement of the liver as a result of acclimation to prolonged cadmium exposure are discussed.

1985 - Use of laboratory studies in assessing the behaviour of contaminants in fish inhabiting natural ecosystems. Wat.Pollut.Res.J.Can., 20(1) :79-88.

The behaviour of environmental contaminants in fish was examined using information from chemical, toxicological, and physiological laboratory studies, and field residue measurements to establish the relative importance of the bioconcentration and biomagnification pathways, and environmental concentrations on residue accumulation in natural ecosystems. It is suggested that indices such as the bioconcentration factor (BCF) and octanol-water partition coefficient (K_{OW}) can be effectively used to analyse the fate of contaminants in natural ecosystems provided their limitations are recognized. It is proposed that other indices like the bioaccumulation factor (BAF) and biological half-life could also be used for evaluation. A simulation of the contaminant dynamics of a salmonid is presented, and the kinetics are used to illustrate the differences in behaviour of the more environmentally relevant organic contaminants present in the Lake Ontario environment.

1985 - OLIVER, B.G., & NIIMI, A.J. Bioconcentration factors of some halogenated organics for rainbow trout: limitations in their use for prediction of environmental residues. Environm.Sci.Technol., 19:842-849.

The bioconcentration factors, BCF's, for 34 chlorinated and brominated chemicals in rainbow trout have been determined by the steady-state approach by using chemical water concentrations in the nanogram per liter range. In addition, for 13 chemicals with a known half-life in trout, BCF's were also estimated by using the kinetic approach. The two methods gave comparable results for compounds with short half-lives in the fish but significantly different results for

NIIMI, A.J.(cont.)

longer half-life chemicals .The BCF's have been shown to correlate well with octanol/water partition coefficients K_{ow} for many of the study compounds. But the BCF's of high molecular weight compounds and compounds metabolized by the fish did not correlate with K_{ow}. The laboratory-derived BCF's were compared to field-derived BCF's for Lake Ontario rainbow trout. This comparison showed that predictions based on laboratory BCF's were useful for chemicals with short half-lives in fish but were much too low for long half-life chemicals, where contaminated food is the major chemical source.

1985 - with PALAZZO, V. Temperature effect on the elimination of pentachlorophenol, hexachlorobenzene and mirex by rainbow trout (Salmo gairdneri). Wat.Res., 19(2):205-207.

The elimination rates of pentachlorophenol, hexachlorobenzene and mirex were estimated in rainbow trout that were held at 4, 12 and 18°C for 120 days following a single oral exposure. The results suggested temperature could become an important environmental variable in deriving a coefficient for the elimination component of a contaminant dynamics model. This response would be most applicable for those substances that are eliminated relatively rapidly, and those models that simulate the contaminant dynamics of fish in its natural environment.

1986 - LOWE-JINDE, L., & NIIMI, A.J. Hematological characteristics of rainbow trout, Salmo gairdneri (Richardson), in response to cadmium exposure. Bull.Environm.Contam.Toxicol., 37:375-381.

In this study the spleen somatic index, total and differential erythrocyte and leucocyte counts in cadmium-exposed rainbow trout were measured. The lower working concentrations include levels (1.5 - 6.3 µg Cd/L) recommended by the USEPA (1980) for protection of freshwater aquatic life.

1986 - Commerce on the rocks: winter navigation. Alternatives, 13(3):42-45.

1986 - Biological half-lives of chlorinated diphenyl ethers in rainbow trout (Salmo gairdneri). Aquatic Toxicol., 9:105-116.

Biological half-lives of 16 trichloro- to decachlorodiphenyl ether isomers were determined in rainbow trout (Salmo gairdneri). A whole body half-life of 63 days was estimated for a trichloro-isomer. Values for tetrachloro- to heptachloro-isomers generally exceeded 100 days, and mean values among the congeners increased with chlorine content. A half-life of 46 days was determined for the decachloro-isomer. Absorption efficiencies ranged from 13-65 percent of the oral dose administered, and mean values among congeners generally decreased with increasing chlorine content. These results were compared with similar studies on polychlorinated biphenyls, dibenzofurans, and dibenzodioxins.

1986 - with OLIVER, B.G. Biological half-lives of chlorinated dibenzo-p-dioxins and dibenzofurans in rainbow trout (Salmo gairdneri). Environm.Toxicol.Chem., 5:49-53.

NIIMI, A.J. (cont.)

The biological half-lives of five dibenzo-p-dioxins and two dibenzofurans were determined in rainbow trout following a single oral exposure. Estimated half-lives ranged from 2 d for 2,7-dichlorodibenzo-p-dioxin to 43 d for 1,2,3,4-tetrachlorodibenzo-p-dioxin among the dioxins, and from 12 d for octachlorodibenzofuran to 24 d for 3,6-dichlorodibenzofuran. No consistent relationship was shown between half-life and the degree of chlorination. Absorption efficiencies varied from 2 to greater than 30 percent, although most values ranged from 5 to 16 percent.

1986 - with PALAZZO, V. Biological half-lives of eight polycyclic aromatic hydrocarbons (PAHs) in rainbow trout (*Salmo gairdneri*). Wat.Res., 20(4):503-507.

Adult rainbow trout were exposed to a single oral dose containing a mixture of eight PAHs, and fish were sampled at intervals between 5-48 days after exposure. Regression analyses on whole fish indicate levels declined significantly in four of the compounds monitored. Their biological half-lives were estimated as nine days for phenanthrene, seven days for fluorene and anthracene and six days for fluoranthene. No reliable estimates could be derived for benzo(a)pyrene, benz(a)anthracene, chrysene or pyrene because of low or nondetectable concentrations at the first sample interval although it could be suggested that their half-lives would be less than several days. The data also suggested that these PAHs are poorly absorbed by trout.

RALPH, K.M.

1983 - Complexation and toxicity of copper and the free metal bioassay technique. See under BORGMANN, U.

1984 - Copper complexation and toxicity to freshwater zooplankton. See under BORGMANN, U.

1985 - Feeding, growth, and particle-size-conversion efficiency in white sucker larvae and young common shiners. See under BORGMANN, U.

1986 - Effects of cadmium, 2,4-dichlorophenol, and pentachlorophenol on feeding, growth, and particle-size-conversion efficiency of white sucker larvae and young common shiners. See under BORGMANN, U.

1986 - Early development of the common shiner, *Notropis cornutus* (Mitchill), in southern Ontario. See under LESLIE, J.K.

RHAMEY, J.S.

1984 - Relationship between water solubility of chlorobenzenes and their effects on a freshwater green alga. See under WONG, P.T.S.

1984 - Accumulation and metabolism of tri-n-butyltin cation by a green alga, *Ankistrodesmus falcatus*. See under WONG, P.T.S.

1984 - Ultra-clean techniques in assessing the effects of metals on phytoplankton. See under WONG, P.T.S.

SHEAR, H.

1978 - Lake Superior in the 21st. century. J.Great Lakes Res., 4(3-4):550-553.

Projections of population, industrial growth, phosphorus inputs, changes in land use patterns and waste disposal are given. Phosphorus loadings to the lake from point sources are projected to increase only slightly by the year 2020, assuming all large sewage treatment plants meet a 1 mg/L effluent limitation. Increases in industrial and mining activities could have significant negative impacts on the lake, but these impacts have not been quantified.

1979 - Toxicity of copper to aquatic biota. See under HODSON, P.V.

1980 - WILLIAMS, J.D.H., SHEAR, H., & THOMAS, R.L. Availability to *Scenedesmus quadricauda* of different forms of phosphorus in sedimentary materials from the Great Lakes. Limnol.Oceanogr., 25(1):1-11.

Sedimentary materials from eroding bluffs, suspended solids in streams, and lake bottom sediments from Lakes Ontario and Erie were cultured with the alga *Scenedesmus quadricauda* (Turp.) de Brébisson in modified Rhode's medium with the sediments as the sole source of P. P uptake by the algae was related to the amount of nonapatite inorganic phosphorus in the sediments. Apatite phosphorus was not used, and the bluff samples, in which over 90 percent of total P was in this form, did not support algal growth. The nonapatite inorganic P fraction was highly correlated with the amounts of inorganic phosphorus extracted by three standard techniques for estimating 'available P' (extraction by NaOH and nitrilotriacetic acid solutions and by H-resin) and cell uptake equalled NaOH-extractable inorganic P in several instances. Uptake of P by the cells varied from 8 to 50 percent of total P and from 38 to 83 percent of nonapatite inorganic P when measured directly. Organic phosphorus in the sediments was not utilized by the algae. Percentage utilization of total P was in general highest when total P concentration in the sediments was itself high.

1980 - The needs and objectives of the biological component of a surveillance program. Can.Techn.Rept.Fish.Aquat.Sci., (976):4-13.

The Great Lakes Water Quality Agreement of 1972 specified that the parties shall supply the International Joint Commission with information on the water quality of the Great Lakes. Based on this, the IJC established an extensive surveillance and monitoring program which has, because of the nature of the 1972 Agreement, emphasized physical and chemical parameter measurements. With the signing of the revised Agreement, the opportunity exists to incorporate an expanded biological component including man, into the surveillance program. Some thoughts are given as to the ideal makeup of this biological component, based on past and present surveillance of biota.

1981 - Contaminants programs in the North American Great Lakes Basin. Verh.Internat.Verein.Limnol., 21:1741-1748.

SHEAR, H.(cont.)

As part of the bi-national commitment to contaminants research, two national, one provincial and eight state governments, plus numerous universities are carrying out programs of chemical inventory, toxicological research, analytical methods development, hazard assessment and legislative action to control contaminants. A generalized scheme of the various activities and how they ultimately lead to control measures is given.

1981 - NALEWAJKO, C., LEE, K., & SHEAR, H. Phosphorus kinetics in Lake Superior: light intensity and phosphate uptake in algae. Can.J. Fish.Aquat.Sci., 38:224-232.

Epilimnetic phytoplankton in Lake Superior in September, 1979 had low I_k values (75-190 $\mu E.m^{-2}.s^{-1}$), low N/P ratios (8 to 13.1) and $^{32}PO_4$-P uptake kinetics that were not consistent with a state of extreme phosphorus limitation. Parallel laboratory experiments with Chlorella pyrenoidosa indicated that phosphorus content per cell was higher and uptake rates of phosphate were lower in cells grown under low light (57 $\mu E.m^{-2}.s^{-1}$) than those under high light (340 $\mu E.m^{-2}.s^{-1}$). Maximum $^{32}PO_4$ uptake occured at about 50-60 $\mu E.m^{-2}.s^{-1}$ in both cultures indicating $^{32}PO_4$ uptake kinetics are light dependent at very low light levels, below or close to their I_k values. It appears that light and not phosphorus limited phytoplankton growth in Lake Superior at the time of our experiments. Antecedent solar radiation prior to our experiments coupled with complete mixing of the top 20-25 m of the lake possibly resulted in a low light-adapted phytoplankton population. We suggest that phosphorus control need not be the correct management strategy to maintain oligotrophy in Lake Superior.

1981 - HALLETT, D.J., SHEAR, H., WESELOH,.D.V., & MINEAU, P. Surveillance of wildlife contaminants on the Great Lakes. Verh.Internat.Verein. Limnol., 21:1734-1740.

The use of biological indicator species, such as herring gulls, which represent the top trophic level of the Great Lakes aquatic food web, has proven to be an effective, holistic approach to contaminant monitoring.

Complementary programs acquiring data from predatory fish, and data from sediment are now allowing proper interpretation of the apparent dynamic trends in organochlorine residues within the food chain. Together they should provide an early warning of serious problems related to contaminants which could jeopardize the balance of the Great Lakes ecosystem.

1984 - Contaminants research and surveillance - a biological approach. In: J.O.NRIAGU & M.S.SIMMONS(eds.), Toxic Contaminants in the Great Lakes. John Wiley & Sons, Advances in Environm.Sci.Technol., (14):31-51. ISBN 0-471-89087-1.

1984 - Zooplankton and potential fish production in Lake Ontario. See under BORGMANN, U.

SHRIVASTAVA, H.

1974 - Macrobenthos of Lake Huron. Fish.Res.Bd.Can., Techn.Rept., (449).

Duplicate mud samples were collected by Ponar grab in April and June, 1971, from 72 monitoring stations on Lake Huron. The most abundant groups were Amphipoda (average 340 ind./m^2), Oligochaeta (290/m^2), Sphaeriidae (190/m^2), Gastropoda (35/m^2) and chironomid larvae (35/m^2) . Amphipods, oligochaetes and gastropods were represented by 2, 18 and 9 species respectively. The dominant species were Pontoporeia affinis Lindstrom (Amphipoda) representing 38 percent of the total number of macrobenthos recorded and Stylodrilus heringianus Claparède (Oligochaeta) representing 18 percent. The average number of the total population of macrobenthos was 900 individuals/m^2. The corresponding average for the sublittoral (9-25 m) was 700/m^2, for the epiprofundal (25-100 m) 1080/m^2, and for the profundal (100-200m) it was 720/m^2. The dry weight of the macrobenthos averaged 1.26 g/m^2 for the entire lake. Corresponding values for the sublittoral, epiprofundal and profundal regions were 1.4, 1.35 and 0.7 g/m^2 respectively. The results indicate that the population of Amphipods has decreased and that the population of Oligochaeta has increased substantially since 1952 and 1956. The decrease in Pontoporeia is very evident in the Straits of Mackinac. Depth distribution studies suggest that the range 25-35 m seems to be favourable for all organisms in the Great Lakes. An overall interpretation of the study suggests that Lake Huron currently is in its early phase of mesotrophy.

SPRY, D.J.

1981 - The effects of environmental acid of freshwater fish with particular reference to the softwater lakes in Ontario and the modifying effects of heavy metals. A literature review. See under HODSON, P.V.

THOMAS, R.L.

1977 - ONGLEY, E.D., RALSTON, J.G., & THOMAS, R.L. Sediment and nutrient loadings to Lake Ontario: methodological arguments. Can.J.Earth Sci., 14:1555-1565.

Environmental issues frequently require values for sediment and nutrient loads in river systems. Except in rare instances, such values must be drawn from existing surveillance data which may not reflect sampling strategies pertinent to the issues at hand. In particular, the time variant and nonlinear relationships between discharge and both suspended sediment and sediment-related parameters such as phosphorus cannot be captured in detail by surveillance data. Nevertheless, such data collected routinely by the Ontario Ministry of the Environment accurately reflect the relative loadings both in terms of unit and total yields in five basins where detailed suspended sediment data are available. Although surveillance data underestimate the absolute values of suspended sediment loads calculated from detailed sediment information, these data do capture the relative monthly and seasonal contributions to annual suspended sediment load. A comparison of three methods for calculating annual unit and total loadings of suspended and solute components from surveillance information indicates that annual mean data convey information which is not significantly less adequate than monthly aggregations of data.

1977 - DAMIANI, V., FERRARIO, A., GAVELLI, G., & THOMAS, R.L. Trace metal composition and fractionation of Mn, Fe, S, P, Ba, and Si in the Bay of Quinte freshwater ferro-manganese concretions, Lake Ontario. Proc.Internat.Conf.Interact.Sediments Freshw. :83-93. Amsterdam, Netherlands.

Nodules recovered from seven locations in the Bay of Quinte were analyzed for mineralogical and chemical properties. The distribution of elements within nodules was further analyzed by microprobe. The nodules occured on topographic highs downstream of depositional basins from which the soluble Fe, Mn, and associated elements were derived. Nodules were structured in alternating iron and manganese-rich concentric bands around a central nucleating clast and were composed of geothite, lepidocrocite, psilomelane, and rhodochrosite. Small nodules were found to be iron-rich compared to larger concentrations due to changing conditions in the Bay of Quinte relative to the period of nodule growth. The Bay of Quinte nodules proved to be low in trace metals when compared to concretions from the open waters on the north shore of Lake Ontario.

1978 - with DELL, C.I. Sediments of Lake Superior. J.Great Lakes Res., 4(3-4) :264-275.

406 samples were taken of the surficial three cms of sediment from Lake Superior in 1973. A description of these samples together with the interpretation of continuous echo-sounding records resulted in a description of the surface sediment distribution which is interpreted in the light of the glacial and postglacial evolution of the lake basin. Samples were analyzed for grain size, Eh, pH, organic and inorganic carbon. These parameters are described and related to the modern depositional environment. Eh, pH and organic carbon reflect the current nature of the lake as being oxic, and oligotrophic with low primary productivity. Grain size parameters show distributional trends related to water depth indicating progradation from coarse to fine materials as a function of increasing water depth.

1980 - Availability to *Scenedesmus quadricauda* of different forms of phosphorus in sedimentary materials from the Great Lakes. See under SHEAR, H.

1980 - Sediment investigations as a surveillance tool in the Great Lakes. (Abstract). Can.Techn.Rept.Fish.Aquat.Sci., (976):190.

With correct technique and interpretation open lake sediment properties, both physical and chemical, may be utilized as an adjunct to a surveillance program. Examples of the use of sediment in ascertaining certain characteristics of the Great Lakes

THOMAS, R.L.(cont.)

environment are given as follows: - 1) Historical changes. Examples of metal and nutrient concentrations in core profiles as indicators of historical changes related to the increase in man's activity in the basin; 2) Sources. The use of an anthropogenic compound (mirex) associated with sediment as a means of tracking sources; 3) Impact. By evaluating regional distribution to evaluate the extent of dispersal of contaminants and to determine dispersal pathways and 'sinks'; 4) Quality. The use of multi-variate analyses to define variation and environmental quality based on the overall physical and chemical properties of surface sediments; 5) Context. As a future monitoring strategy for contaminants it would appear to be desirable to use sediment contaminant maps as a sampling base for benthic organisms to evaluate uptake and impact of contaminants at this level of the food web.

1980 - FRANK, R., THOMAS, R.L., HOLDRINET, M.V.H., & DAMIANI, V. PCB residues in bottom sediments collected from the Bay of Quinte, Lake Ontario 1972-73. J.Great Lakes Res., 6(4):371-376.

Surficial sediment samples (214) were collected in 1972-73 on a systematic grid throughout the Bay of Quinte, Lake Ontario. PCB analysis was carried out on all samples and the data were collated for depositional basins and non-depositional zones. The mean residue for the whole bay was 48 ± 43 ng/g. Mean residues in the basins and non-depositional zones were not significantly different, being 50 and 47 ng/g respectively. The Trenton basin had the highest mean residue of 74 ng/g and Adolphous basin had the lowest at 33 ng/g. Variations in concentrations were found within basins and within the non-depositional zone. The over-all distribution was patchy but high concentrations off the Trent River and east of the Moira River indicated these two rivers as the major sources of PCB to the bay.

1980 - FRANK, R., THOMAS, R.L., BRAUN, H.E., RASPER, J., & DAWSON, R. Organochlorine insecticides and PCB in the surficial sediments of Lake Superior (1973). J.Great Lakes Res., 6(2):113-120.

Analysis of 405 Lake Superior surficial sediments (0-3 cm depth) collected in 1973 were found to contain low levels of DDE, HEOD, and PCB, but no detectable mirex, heptachlor epoxide, endrin, endosulfan, or chlordane. p,p'-DDE was detected in 50 percent, HEOD in 9 percent, and PCB in 44 percent of the sediment samples at trace or low measurable levels. Mean residues for the whole lake were p,p'-DDE 0.71 ± 1.65 ng/g, HEOD below the detection level of 0.25 ng/g, and PCB 3.3 ± 5.7 ng/g, p,p'-DDE was more concentrated in depositional basins than in non-depositional zones while PCB levels were similar for the two zones.

1981 - Sediments of the North American Great Lakes. Verh.Internat.Verein. Limnol., 21:1666-1680.

This paper presents a very brief glimpse of some of the ongoing activity in sediment and geochemical research in the Great Lakes. A final sediment distribution map is presented together with some information on sediment texture. From a geochemical standpoint examples are given of vertical and spatial distributions of vanadium, lead and mercury. Vanadium is discussed as a natural element whereas both lead and mercury are given as examples of elements of both natural and anthropogenic origin. In the case of lead, a crude mass balance is provided to identify the major sources of the element. Finally, examples (PCB and Mirex) are given of the utility of sediments as indicators of the occurence and source of man-made organic compounds.

1981 - FRANK, R., THOMAS, R.L., HOLDRINET, H., McMILLAN, R.K., BRAUN, H.E., & DAWSON, R. Organochlorine residues in suspended solids collected from the mouths of Canadian streams flowing into the Great Lakes 1974-1977. J.Great Lakes Res., 7(4):363-381,

Suspended solids were collected from 105 streams on the Canadian side of the Great Lakes during snow melt and spring flow between 1974 and 1977. Analyses were performed for organochlorine and organophosphorus insecticides and three industrial chemicals. All streams sampled contained suspended solids that were contaminated with DDT, its metabolites, and polychlorinated biphenyl (PCB). The highest mean concentrations of ΣDDT (356 μg/kg) occured in 1974 from streams draining the Niagara Peninsula and entering Lake Ontario; these were correlated to areas of high use on fruit in the past. The highest loadings by lake section, however, were along the north shore of Lake Erie involving a very much larger delivery of suspended solids. The highest concentrations of PCB were on suspended solids entering Lake Ontario in 1974 along the northern (191 μg/kg) and southwestern (172 μg/kg) shore and were associated with the high urban-industrial activity in the megalopolis of Hamilton-Burlington-Oakville-Mississauga-Toronto. However, the highest loadings occured along Lake St.Clair where two large rivers, the Thames and Sydenham, discharge a much larger volume of suspended solids. The highest individual concentrations of HEOD (dieldrin) were found on suspended solids in two streams entering along the southwestern shoreline of Lake Ontario. However, the highest mean residues on solids for all streams was in waters entering Lake Erie (3 μg/kg) and the highest loadings were into Lake St.Clair. Endosulfan, chlordane, and heptachlor epoxide were detected in some streams entering all five lakes. No aldrin, endrin, mirex, heptachlor, or organophosphorus insecticides were detected.

1981 - FRANK, R., THOMAS, R.L., BRAUN, H.E., GROSS, D.L., & DAVIES, T.T. Organochlorine insecticides and PCB in surficial sediments of Lake Michigan (1975). J.Great Lakes Res., 7(1):42-50.

Analyses of 286 surficial sediments (0-3 cm), collected in August 1975, were found to contain residues of DDT and its metabolites (ΣDDT), heptachlor epoxide (HE), HEOD (dieldrin), chlordane, and polychlorinated biphenyls (PCB), but no detectable residues of endrin, endosulfan, or methoxychlor. Sixty-two samples were checked for mirex but no residues were detected to a limit of 0.2 ng/g. ΣDDT residues were measurable in 93.4 percent of bottom sediments, HEOD in 48.3 percent, HE in 53.9 percent, chlordane in 21.6 percent, and PCB in 79.6 percent above detection limits for each compound. The

THOMAS, R.L.(cont.)

mean residues for the whole lake were calculated to be 11.9 ng/g ΣDDT, 0.25 ng/g HEOD, 0,67 ng/g HE, 0.37 ng/g chlordane, and 9.7 ng/g PCB. Depositional zones were two to four times higher in the concentrations of these organochlorine compounds than the non-depositional zones. Basins varied in the levels of contamination for the different compounds. ΣDDT was highest in the Milwaukee basin (40.8 ng/g), HEOD was highest in the Waukegan basin (0.77 ng/g), chlordane was highest in the Grand Haven basin (1.47 ng/g), and HE and PCB were highest in the Fox basin (2.70 and 73.5 ng/g). The distribution of ΣDDT conformed well with the depositional basins of the lake as related to the redistribution of sediment following restrictions on DDT use. For HEOD, HE, and PCB the sediment distributions indicated active usage in 1975 and the probable location of loading sources.

1983 - The impact of sediment-associated contaminants from the Niagara River mouth on various size assemblages of phytoplankton. See under MUNAWAR, M.

1983 - GOLTERMAN, H.L., SLY, P.G., & THOMAS, R.L. Study of the relationship between water quality and sediment transport. UNESCO, Techn.Pap.Hydrol., (26). ISBN 92-3-102109-5.

This publication has been prepared in the form of a guidebook; it explains how sediments may influence water quality or, in turn, how the composition of sediments may be influenced by water quality. It shows how to evaluate the importance of sediments in aquatic systems (such as rivers, lakes, and estuaries) and it explains how sediment analyses may be used together with, or as an alternative to, water quality data as indicators of environmental conditions. It also explains the special value of sediment data in providing both a historical record and a register of transient events, as well as a means of providing a source of naturally-integrated environmental data. Sediments may also provide a means of concentrating certain contaminants, thereby allowing the use of less sensitive measuring techniques than might otherwise be necessary for the characterization of water quality at low concentrations.

This guidebook has been prepared to assist in the design, sampling, analysis, and interpretation of sediment studies in rivers, streams, lakes, ponds, and estuaries, particularly where such studies are being initiated for the first time or where the work is being undertaken by water quality staff not previously experienced in sediment studies.

1984 - An overview of sediment-associated contaminants and their bioassessment. See under MUNAWAR, M.

1984 - Lead contamination of the Great Lakes and its potential effects on aquatic biota. See under HODSON, P.V.

1985 - with MUNAWAR, M. The delivery and bioavailability of particulate bound phosphorus in Canadian rivers tributary to the Great Lakes. In; J.N.LESTER & P.W.W.KIRK(eds.), Management Strategies for Phosphorus in the Environment: 462-469. Proc.Internat.Conf., 1-4 July, Lisbon, 1985.

THOMAS, R.L.(cont.)

Canadian rivers draining into the Great Lakes were sampled for suspended solids during spring run-off and a further ten rivers sampled monthly for a year. Samples were analyzed for major elements, total phosphorus (TP), apatite phosphorus (AP), organic phosphorus (OP), and non-apatite inorganic phosphorus (NAIP). NAIP and OP concentrations show a high degree of variability as compared to AP which is indicative of a stable phosphorus background in the watershed. The influence from upstream urban areas in the Lake Erie drainage basin can be seen, indicating a residual effect of upstream point sources.

1985- Toxicity of Detroit River sediment-bound contaminants to ultraplankton. See under MUNAWAR, M.

TIMMINS, C.A.

1983 - Seine for sampling larval fish in shallow water. See under LESLIE, J.K.

1986 - Occurence and spawning of pink salmon, Oncorhynchus gorbuscha in Lake Ontario tributaries. See under DERMOTT, R.M.

VALLENTYNE, J.R.

1984 - Towards a symbol for the world campaign for the biosphere. Environm.Conserv., 11(4):309-312.

Criteria in selecting a symbol for the World Campaign for The Biosphere are analyzed around fourteen questions posed to the World Council For The Biosphere (WCB) and the International Society for Environmental Education (ISEE) . To be truly supranational the symbol must be free from words and focused on mind and The Biosphere - the key end-points in the circular causal chain of 'education for ecologically sustainable development'. As the target audience is external to WCB-ISEE, the symbol should be open to use by other organizations, and perhaps have a designated place for their identification. To the extent that the symbol poses a moral question it should be spiritual, emotive, and applicable to instances of overexploitation and excessive waste. Technology should not be automatically excluded, nor should the focus be restricted to organizations (versus people) or specific age-groups.

The essential message to be communicated is wholeness through feedback. Suitable geometric forms include irregular lines ending where they begin, circles, spheres, and (in terms of computer imagery) pulsating objects. Existing symbols with appropriate traditions to build on include: the yin-yang symbol of the Tao; The Atlas symbol of person-planet; individual life-forms such as a tree; and the glory - the shadow of a human head surrounded by concentric, rainbow-coloured circles.

1984 - Johnny Biosphere. Environm.Conserv., 11(4):363-364.

1986 - CHRISTIE, W.J., BECKER, M., COWDEN, J.W., & VALLENTYNE, J.R. Managing the Great Lakes basin as a home. J.Great Lakes Res., 12(1):2-17.

VALLENTYNE, J.R.(cont.)

The ecosystem approach, a more holistic way to planning, research, and management of the Great Lakes basin, was articulated as a concept in the 1978 Great Lakes Water Quality Agreement. In order to stimulate movement of this concept to a series of implementable actions, an Ecosystem Approach Workshop was held in March 1983. This paper describes the process used to define common cause for a group of 56 participants representing a diverse spectrum of backgrounds. Three generic obstacles to attainment of an ecosystem approach, which emerged from pre-workshop efforts, were addressed by the workshop. They were: (1) lack of an holistic perspective, (2) predominance of 'egosystem' thinking, and (3) lack of a preventive approach. The strategy suggested for overcoming the obstacles was identified as 'enlightened self-interest'. The participants proposed 33 initiatives for advancing the ecosystem approach. These initiatives related to improving the acquisition of scientific data, directing institutional change for ecosystem management, improving citizen participation, paying the costs for resources use, education, and public awareness. In order to help implement these initiatives, establishment of an ecosystem approach monitoring group and an improved public information program is recommended.

1986 - International Year of the Biosphere. The Biosphere, (4):1-2.

VOLLENWEIDER, R.A.

1970 - Distribution of trace elements and chlorophyll a in Lake Ontario. See under NICHOLSON, H.F.

1972 - The seasonal cycle of phaeopigments in Lake Ontario with particular emphasis on the role of zooplankton grazing. See under GLOOSCHENKO, W.A.

1973 - Chlorophyll a distribution in Lake Huron and its relationship to primary production. See under GLOOSCHENKO, W.A.

1974 - with MUNAWAR, M., & STADELMANN, P. A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. J.Fish.Res.Bd.Can., 31:739-762.

Species composition of phytoplankton in the Laurentian Great Lakes, its biomass concentration, and its physiological activity measured as photosynthesis related to eutrophication, are reviewed and discussed.

1974 - GÄCHTER, R., VOLLENWEIDER, R.A., & GLOOSCHENKO, W.A. Seasonal variations of temperature and nutrients in the surface waters of Lakes Ontario and Erie. J.Fish.Res.Bd.Can., 31:275-290.

During 1970, temperature and nutrient distributions were measured in surface waters of Lakes Ontario (12 cruises) and Erie (10 cruises). Nutrient patterns are compared and discussed in relation to temperature, primary production, and nutrient sources.

In Lake Erie, due to the early onset of the phytoplankton spring bloom, nutrient concentration started to decrease much earlier than

VOLLENWIEDER, R.A.(cont.)

in Lake Ontario. During spring, patterns of nutrients, chlorophyll *a*, and primary production were influenced by the thermal bar in Lake Ontario. In Lake Erie the nutrient supply controlled such patterns. In Lake Erie inorganic nutrients were depleted lake-wide in summer; in Lake Ontario, nutrients were highest in regions where upwelling occured or inputs were high. Due to the earlier onset of fall overturn in Lake Erie, the nutrient concentration started to increase earlier in the fall than in Lake Ontario.

1974 - Primary production in Lakes Ontario and Erie: a comparative study. See under GLOOSCHENKO, W.A.

1974 - Spatial and temporal distribution of chlorophyll *a* and phaeopigments in surface waters of Lake Erie. See under GLOOSCHENKO, W.A.

WATSON, N.H.F.

1974 - Zooplankton of the St.Lawrence Great Lakes - species composition, distribution, and abundance. J.Fish.Res.Bd.Can., 31:783-794.

Recent studies of zooplankton of the St.Lawrence Great Lakes have concentrated on a broad synoptic coverage of sampling stations and repeated cruises throughout a growing season. This has resulted in a considerable amount of detail about seasonal changes in species composition, total numbers, and vertical and horizontal distributions. Investigators have treated the data to show differences in distribution over the lakes on a cruise and cruise mean averages for each lake, often weighted by area to provide relative abundance figures over the season and between lakes.

Maximum numbers were observed in Lake Erie (225,000/m^3). Considerably fewer organisms were found in periods of peak abundance in Lake Ontario (55,000/m^3) and Lake Huron (22,000/m^3). No firm estimates are available for Lake Superior but numbers from one cruise (8,000/m^3) indicate still lower values there. Biomass estimates (either as ash-free weight of material from plankton net hauls or from conversion of numbers to biomass from dry weight factors for individual species) are highest for Lake Erie, but reflect the larger size of organisms in the other lakes, especially Huron and Superior.

Species distributions are now reasonably well known for crustaceans, except in one or two taxa of the cladocerans *Daphnia* and *Bosmina* whose variability should be investigated more fully. Recent studies have been made on the rotifers, but their numbers, distribution, and ecological role is not fully defined. Similarly, the distribution and role of protozoan groups have been largely ignored.

Several computer techniques are suggested for the handling and analysis of the large quantities of data generated on lakewide surveys including community coefficients and cluster analyses. More attention should be given to determining sampling intervals to obtain information which can precisely detect changes in abundance from year to year, and better population dynamics and production data are needed to relate zooplankton stocks to eutrophication.

WATSON, N.H.F.(cont.)

1974 - with CARPENTER, G.F. Seasonal abundance of crustacean zooplankton and net plankton biomass of Lakes Huron, Erie, and Ontario. J.Fish.Res.Bd.Can., 31:309-317.

Crustacean zooplankton concentrations (numbers per m^3) in the upper 50 m found in lakewide cruises during all or most of the seasons on Lakes Ontario and Erie in 1970 and on Lake Huron in 1971 showed that the species of zooplankton crustaceans present in the three lakes were generally identical, although the times of maxima and relative species composition differed. Calanoid copepods were most abundant and diverse in Lake Huron and western Lake Erie. Cyclopoids and cladocerans were most abundant in Lakes Erie and Ontario and in the Saginaw Bay region of Lake Huron. The most abundant cyclopoid throughout the year in all three lakes was *Diacyclops bicuspidatus thomasi*; *Tropocyclops prasinus* and *Acanthocyclops vernalis* were abundant especially in Lakes Ontario and Erie, respectively. Cladocerans were most numerous in Lakes Erie and Ontario. Numbers of individuals fluctuated markedly through the season with maxima in the spring or summer months in all three lakes.

Biomass values (ash-free dry weight) were highest in Lake Erie, especially the western basin, and in Saginaw Bay of Lake Huron. Although numbers of crustaceans/m^3 were much lower in Lake Huron than in Lake Ontario, net biomass values were similar, This was due to the greater size and average weight of crustaceans in Lake Huron samples. Inshore waters of Lakes Ontario and Huron and all three basins of Lake Erie were subject to greater fluctuations in concentrations of crustacean zooplankton and net biomass values than in the pelagic waters of Lakes Ontario and Huron.

1974 - Abundance and life history of *Mysis relicta* in the St.Lawrence Great Lakes. See under CARPENTER, G.F.

1974 - THOMAS, N.A. & WATSON, N.H.F. Biology-chemistry program for the International Field Year for the Great Lakes. Proc.IFYGL Symp., 55th.Ann.Meet.Amer.Geophys.Union 1975:146-156.

1975 - with CARPENTER, G.F., & MUNAWAR, M. Problems in the monitoring of biomass. In; *Water Quality Parameters*, Amer.Soc.Test.Materials, Spec.Techn.Publ., (573):311-319 .

Two general approaches for the estimation of standing crop for biomass determinates have been attempted in fresh waters. One involves identification and enumeration of organisms and subsequent extrapolation to biomass from volumetric or weight factors. Several direct methods are available for determining biomass, all of which give results affected by sample size but do not discriminate between types of organisms present. Some samples from current Great Lakes research are presented.

1975 - with CULP, L.R., & NICHOLSON, H.F. Chlorophyll *a* and primary production in Georgian Bay, North Channel and Lake Huron, April to December, 1974. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (600).

WATSON, N.H.F.(cont.)

Chlorophyll a measurements were made during seven cruises between April and December 1974 in Georgian Bay, Lake Huron (north of 45°30' latitude), and North Channel. Carbon-14 uptake measurements were also made in Georgian Bay and North Channel between April and October. Carbon uptake values were converted to daily production rates per m^2 of surface area. Annual primary production estimates were computed from chlorophyll a and carbon uptake data.

Georgian Bay cruise means of corrected chlorophyll a ranged from 0.7 μg/l to 1.7 μg/l; individual station values ranged from 0.3 μg/l to 5.6 μg/l. Primary production values varied from 1.0 mg C/m^3/hr to 14.5 mg C/m^3/hr, which convert to 0.03 g C/m^2/day to 0.51 g C/m^2/day with a cruise mean range from 0.09 g C/m^2/day to 0.29 g C/m^2/day. Annual primary productivity was estimated at 76 g C/m^2/yr, using the mean uncorrected chlorophyll a value, and 35 g C/m^2/yr, using carbon-14 cruise means extended to zero winter values.

North Channel cruise means of corrected chlorophyll a ranged from 1.3 μg/l to 2.3 μg/l; individual station values ranged from 0.8 μg/l to 3.7 μg/l. Primary production values varied from 1.3 mg C/m^3/hr to 5.5 mg C/m^3/hr which convert to 0.04 g C/m^2/day to 0.44 g C/m^2/day with a cruise mean range from 0.12 g C/m^2/day to 0.32 g C/m^2/day. Annual primary productivity was estimated at 92 g C/m^2/yr, using the mean uncorrected chlorophyll a value and 37 g C/m^2/yr, using carbon-14 cruise means extended to zero winter values.

Lake Huron cruise means for corrected chlorophyll a ranged from 1.0 μg/l to 2.3 μg/l, with station values ranging from 0.4 μg/l to 4.0 μg/l. Estimated annual primary production from the uncorrected chlorophyll mean was 92 g C/m^2/yr.

1975 - with NICHOLSON, H.F., & CULP, L.R. Chlorophyll a and primary production in Lake Superior, May to November, 1973. Can.Dept.Environm., Fish.Mar.Serv., Techn.Rept., (525).

Chlorophyll a and carbon-uptake studies from six lakewide cruises on Lake Superior from May to November, 1973, are presented. A maximum of 6.6 μg/l in September and a minimum of 0.3 μg/l in May of chlorophyll a (corrected for phaeophytins) and a range of cruise means of 0.9 - 1.4 μg/l was determined. C^{14}-uptake measurements showed a range of 0.3 to 5.7 mgC/m^3/hr with carbon production having a range of 0.003 to 0.54 gC/m^2/day. Integration of the cruise means with time produced a minimal annual estimate of 30 gC/m^2/year.

1975 - with THOMSON, K.P.B., & ELDER, F.C. Sub-thermocline biomass concentration detected by transmissometer in Lake Superior. Verh.Internat.Verein.Limnol., 19:682-688.

It seems reasonable to conclude that whatever the physical and chemical conditions which cause them to do so, considerable quantities of phytoplankton algae may accumulate at depths just below the thermocline and the bottom of photic zone in large, deep lakes. Estimates of production of these bodies of water based on sequential synoptic surveys of surface or mean epilimnion

WATSON, N.H.F. (cont.)

concentrations of phytoplankton biomass may underestimate the production considerably.

The inherent value of optical density sensing techniques, transmissometers and fluorometers has been demonstrated in the literature of these microstratifications and the use of these instruments and others is likely to add to our knowledge of the existence and causes of these interesting discontinuities in the vertical structure of lakes.

1976 - Seasonal distribution and abundance of crustacean zooplankton in Lake Erie, 1970. J.Fish.Res.Bd.Can., **33**:612-621.

The lakewide horizontal distribution and seasonal abundance of the cyclopoids, cladocerans, and calanoids in Lake Erie from April to December 1970 are presented.

Over much of the year cyclopoids dominated by *Diacyclops bicuspidatus thomasi* were most numerous with offshore centers of abundance. Several species of cladocerans, often with short peaks of occurence, were most abundant during summer in the western basin and associated with south shore population centers in the central basin. Calanoids were frequently much less abundant than either of the two groups but present in the same areas as the cladocerans.

Most species present were short-lived with a high reproductive potential. Environmental clues are postulated to control specific abundance making group numbers more constant. Several life-cycle patterns were evident including species with spring-fall maxima and those with a single peak.

Timing of peak abundance of certain species and groups varies from west to east in the same fashion as temperature differences giving rise to east-west gradients of abundance which change with season. Cladoceran and calanoid groups show similarities in distribution pattern with estimates of particulate organic material rather than with algal abundance resulting in north-south gradients of abundance.

1976 - Processes within Lake Erie. See under **MUNAWAR, M.**

1977 - CARTER, J.C.H., & **WATSON, N.H.F.** Seasonal and horizontal distributions of planktonic crustacea in Georgian Bay and North Channel, 1974. J.Great Lakes Res., **3**(1-2):113-122.

Samples taken from Georgian Bay and North Channel from April to December, 1974, were analyzed with respect to species composition and abundance, and seasonal and horizontal distribution. Eleven species of Cladocera and 12 of Copepoda were found. *Cyclops bicuspidatus thomasi* comprised more than 50 percent of all planktonic crustacea. Warm surface waters accumulated in the northern and eastern parts of Georgian Bay and the eastern end of North Channel in late spring and early summer probably contributed to the high abundance of cladocerans in those regions during that period. Horizontal distributions of both cyclopoid and calanoid copepods showed no positive relationship to temperature and were probably a consequence of transportation by water currents. Mean summer abundance of planktonic Crustacea in Georgian Bay and North

WATSON, N.H.F.(cont.)

Channel in 1974 was slightly higher than that in Lake Superior but much lower than that in Lake Huron during 1968.

1978 - with WILSON, J.B. Crustacean zooplankton of Lake Superior. J.Great Lakes Res., 4(3-4):481-496.

Six lake-wide surveys were carried out on Lake Superior between May and November of 1973. The zooplankton population was found to be dominated by calanoids, and total abundance was generally low in comparison with the lower Great Lakes. Little variation was seen in total numbers/m^3 through the sampling season, but total biomass increased five-fold between May and September. The lake appeared to support a permanent year-round lake-wide community composed of Diacyclops bicuspidatus thomasi and the larger calanoid species. This community was augmented annually by a succession of summer forms which developed initially inshore and then spread to various degrees into the offshore waters. The zooplankton data were fitted to the fifteen zones defined by previous authors. This procedure showed the zooplankton community to be quite heterogeneous with greatest abundances being found in the inshore zones. Seasonal cycles of both numbers and biomass varied widely, but zone patterns could easily be grouped by general geographic area. The use of zone averages revealed a strong correlation between zooplankton biomass and surface water temperature. Cluster analysis was used to independently define regions of similar species composition. This procedure revealed that the zooplankton community was relatively homogeneous throughout the lake in the spring. Local clusters appeared in many inshore areas during the early summer and, by early fall, the zooplankton community distribution was heterogeneous. Homogeneous conditions returned quickly with the late fall turnover. Most of the inshore regions occured adjacent to areas of probable land-use effects. The life histories of selected major species were examined in cases where sampling and identification procedures permitted their analysis.

WHITTLE, D.M.

1977 - FOX, M.E., WHITTLE. D.M., & KAISER, K.L.E. Dehydroabietic acid accumulation by rainbow trout (Salmo gairdneri) exposed to kraft mill effluent. J.Great Lakes Res., 3(1-2):155-158.

Rainbow trout (Salmo gairdneri) were examined for the presence of dehydroabietic acid after exposure to kraft mill effluent. Levels of 2 to 10 µg/g dehydroabietic acid on a whole fish wet weight basis were found in fish exposed to 3 to 18 percent effluent for 48 to 144 hours. Less than 1 µg/g dehydroabietic acid was found in control fish which had been acclimated in Nipigon Bay water for two weeks and no residue was detected in an unexposed fish. It is concluded that fish exposed to kraft mill effluent accumulate dehydroabietic acid to a level which is likely to result in sublethal toxic effects.

1980 - Contaminants in fish and other biota: Lower Great Lakes. Can.Techn.Rept.Fish.Aquat.Sci., (976):189. (Abstract).

WHITTLE, D.M.(cont.)

Samples of fish, total net plankton (153 μmesh) and a single species of zooplankton, Mysis relicta, were collected during 1977 from 10 locations on the Lower Great Lakes. All samples were analyzed on an individual basis for lipid content, polychlorinated biphenyls, and a range of organochlorine pesticides and trace metals. A majority of fish samples were analyzed on both a whole fish and edible portion basis. The ratio between individual contaminant levels in each of the two sample types was investigated for each species.

By utilizing these relationships together with the extensive data base on edible portion contaminant levels, the feasibility of providing historical information on total body burdens and extrapolating to provide trend information is discussed.

Other data presented describe the relationships between contaminant levels in some fish species and their major dietary items.

1980 - Biochemical monitoring of fish blood as an indicator of biologically available lead. See under HODSON, P.V.

1982 - Effect of growth rate and size of fish on rate of intoxication by waterborne lead. See under HODSON, P.V.

1983 - Particle-size-conversion efficiency and contaminant concentrations in Lake Ontario biota. See under BORGMANN, U.

1983 - with FITZSIMONS, J.D. The influence of the Niagara River on contaminant burdens of Lake Ontario biota. J.Great Lakes Res., 9(2):295-302.

Two predator and forage fish species, netplankton (>153 μm), zooplankton, and benthic macroinvertebrates from Lake Erie and Lake Ontario were analyzed for whole body levels of trace metals and organic contaminants. Comparison of contaminant concentrations in similar aquatic food chains from both lakes indicated that levels of PCB, DDT, mirex, and mercury are significantly greater ($P<0.05$) in the biota of Lake Ontario. The Niagara River, the single largest tributary to Lake Ontario, was confirmed as a major source of organic contaminants and trace metals. Organic contaminants are adsorbed to the particulate load of the river and dispersed throughout Lake Ontario by the circulating currents. There was no significant regional difference ($P<0.05$) in the degree of contaminant accumulation by the pelagic food chain of Lake Ontario. Conversely, both inorganic and organic contaminant levels in the demersal amphipod, Pontoporeia affinis, were significantly different ($P<0.05$) between the eastern and western basins of Lake Ontario. The uptake and concentration of contaminants at the sediment-water interface is suggested as a possible mechanism to explain this observed difference.

1983 - The suitability of a biochemical method for assessing the exposure of feral fish to lead. See under HODSON, P.V.

WHITTLE, D.M.(cont.)

1983 - BODDINGTON, M.J., DOUGLAS, V.M., DUNCAN, C.E., GILBERTSON, M., GRANT, D.L., HALLETT, D., McCLELLAND, L., ROBERTS, J.R., SINGH, J., & WHITTLE, M. Dioxins in Canada. Chemosphere, 12(4/5):477-480.

In summary, Canada is active in a wide variety of research efforts into PCDDs and PCDFs while at the same time trying to generate policies and directions for the future that will ameliorate the problems thus far identified.

1984 - Monitoring lead exposure to fish. See under HODSON, P.V.

1984 - Selenium contamination of the Great Lakes and its potential effects on aquatic biota. See under HODSON, P.V.

1984 - Lead contamination of the Great Lakes and its potential effects on aquatic biota. See under HODSON, P.V.

1986 - Biological tissue archive studies. See under HYATT, W.H.

WONG, P.T.S.

1974 - KAISER, K.L.E., & WONG, P.T.S. Bacterial degradation of polychlorinated biphenyls. I. Identification of some metabolic products from Aroclor 1242. Bull.Environm.Contam.Toxicol., 11:291-296.

Polychlorinated biphenyls (PCB's) have been recognized as worldwide pollutants with important biological activity and effects upon the aquatic ecosystem. Residual mixtures of the highest chlorinated isomers, i.e. trichloro- to octachloro-biphenyls can be traced in many species of fishes, and in fish-eating birds within the American and European continents, as well as across the Atlantic. Though there are several reports on the effects of polychlorinated biphenyls on the metabolism of aquatic and terrestric organisms, only recently has the metabolic degration of PCB's themselves been found of interest. Evidence was found in 1972 for a rapid metabolism of the less chlorinated isomers of Aroclor 1242 mixtures on feeding it to pigeons and quails. The degradation of PCB by two species of *Achromobacter* has been described. The mechanism of the PCB degradation by the affected organisms, however, has not been investigated and therefore, studies were initiated to investigate the biodegradation of PCB's, their kinetic and mechanistic differences with respect to different aquatic organisms.

1975 - CHAU, Y.K., WONG, P.T.S., & GOULDEN, P.D. Gas chromatography -atomic absorption method for the determination of dimethyl selenide and dimethyl diselenide. Anal.Chem., 47:2279-2281.

The present study describes the combination of a gas chromatograph and an atomic absorption spectrophotometer for the analysis of dimethyl selenide and dimethyl diselenide at nanogram level. In addition to its high sensitivity, the system has the advantages of efficient separation and very high specificity. We developed this method primarily to analyze the biologically-generated volatile

WONG, P.T.S.(cont.)

selenium compounds in the atmosphere of lakewater sediment systems. It can also be readily applied to analyze these compounds in air samples.

1975 - with KAISER, K.L.E. Bacterial degradation of polychlorinated biphenyls. II. Rate studies. Bull.Environm.Contam.Toxicol., 13(2):249-256.

In our previous paper (1974) we described metabolic products of Aroclor 1242 degradation by bacterial isolates. In this investigation, we report on the toxicity of three Aroclors to lake water bacteria and the relative rates of degradation of Aroclor 1221, biphenyl, 2-chlorobiphenyl and 4-chlorobiphenyl by these bacteria.

1975 - with CHAU, Y.K., & LUXON, P.L. Methylation of lead in the environment. Nature, 253(5489):263-264.

We conclude from the results of 50 experiments that incubation of some lead containing sediments generates Me_4Pb; that Me_3Pb^+ salts are readily converted to Me_4Pb by microorganisms in lake water or nutrient medium, with or without the sediment, and in the presence or the absence of light; that conversion of inorganic lead (such as lead nitrate or lead chloride) to Me_4Pb occured on several occasions in the presence of certain sediments; and that the conversion is purely a biological process.

1975 - with CHAU, Y.K., LUXON, P.L., & SILVERBERG, B. Methylation of lead and selenium in the environment. Proc.Internat.Conf.Heavy Metals Environm., Toronto:C220-C221. (Abstract).

Microorganisms from several lake sediments were found to be capable of transforming certain inorganic and organic lead compounds into a volatile tetramethyl lead at a maximum rate of six percent of lead per week. Tetramethyl lead was more toxic to algae than inorganic lead compounds as shown by cell growth, primary productivity and ultra-structural changes.

Methylation of selenium by microorganisms was also observed. Three volatile selenium compounds, dimethyl selenide, dimethyl diselenide and one unidentified compound were produced by the microorganisms from several selenium compounds under aerobic conditions.

1976 - SILVERBERG, B.A., WONG, P.T.S., & CHAU, Y.K. Ultrastructural examination of *Aeromonas* cultured in the presence of organic lead. Appl.Environm.Microbiol., 32:723-725.

Aeromonas sp will methylate trimethyl lead acetate (Me_3PbOAc) to volatile tetramethyl lead (Me_4Pb). Examination of cultures grown in the presence of Me_3PbOAc revealed no major irregularities between cells of the treated and untreated cultures. Some cells, however, showed evidence that intracytoplasmic materials had been leached from the cells. The lead-treated cells were interpreted to contain lead ions on the basis of energy-dispersive X-ray analysis.

WONG, P.T.S.(cont.)

1976 - SILVERBERG, B.A., WONG, P.T.S., & CHAU, Y.K. Localization of selenium in bacterial cells using TEM and energy dispersive X-ray analysis. Arch.Microbiol., 107:1-6.

Bacteria isolated from lake sediment samples reduced sodium selenite to elemental selenium. Fine-structural observations were made on a number of different bacterial species cultured in the presence of sodium selenite. Examination of Escherichia coli and a Pseudomonas species revealed electron-dense deposits of irregular shape, composed of smaller units, within the cytoplasm but not on the cell wall and cell membrane. Cells of Aeromonas and Flavobacterium species exhibited conspicuous intranuclear fibrillary aggregates and different electron-dense inclusions. It appeared that the membrane structures were somewhat more easily stained in some bacterial cells after growth on agar plates containing sodium selenite. The deposits and fibrillary accumulations were interpreted to contain selenium on the basis of energy dispersive X-ray analysis. Control preparations and cells grown in the presence of sodium selenate were void of any fine-structural abnormalities. Alterations in fine structure are discussed in relation to the metabolism of selenium by bacterial cells and possible sites of inhibition.

1976 - NRIAGU, J.O., & WONG, P.T.S. Fractionation of sulfur isotopes by algae. In; E.R.KLEIN & P.D.KLEIN(eds.), Proceedings of the 2nd. International Conference on Stable Isotopes:734-738. U.S. Dept. Commerce, Techn.Inform.Serv., Springfield, Virginia.

Chlorella grown in a large pool of the sulfate can accumulate considerably more sulfur than is required for growth. The metabolic sulfate uptake is accompanied by preferential removal of the lighter ^{32}S isotope. The isotope fractionation factor between the cells and the initial solution is constant (6 per mil) and much larger than is generally believed. Selective transport of ^{32}S across the cell membranes is believed to be responsible for the observed isotopic effects.

1976 - CHAU, Y.K., & WONG, P.T.S. Complexation of metals in natural waters. In; R.W.ANDREW, P.V.HODSON & D.E.KONASEWICH(eds.), Toxicity to Biota of Metal Forms in Natural Waters:187-196. Internat.Joint Comm., Windsor, Ont.

A significant fraction of the trace metals in natural waters is believed to exist in complexed forms with the miscellaneous organic ligands which regulates the availability of these metals in the system. The abundance and characteristics of the ligands determine the complexing capacity of the water, hence, its regulating capability. The paper discusses the forms of metals, toxic effects, complexing capacity of natural water and its effect in ameliorating metal toxicity.

1976 - CHAU, Y.K., WONG, P.T.S., & GOULDEN, P.D. Gas chromatography-atomic absorption spectrometry for the determination of tetraalkyllead compounds. Anal.Chim.Acta, 85:421-424.

WONG, P.T.S.(cont.)

The combination of gas chromatography and atomic absorption spectrometry has proved to be an excellent system for the determination of volatile organometallic compounds such as tetraalkyllead and dimethyl selenide compounds. In a previous method for tetraalkyllead compounds, the g.c.-flame a.a.s. combination showed a detection limit of about 0.1 µg Pb. Recent investigations have shown that by using a silica furnace in the a.a.s. unit, the sensitivity can be enhanced by three orders of magnitude. The present communication describes the use of the furnace in analysis for tetraalkyllead compounds. This method was developed for the study of conversion of lead compounds to tetraalkyllead in sediment systems. It can be applied readily to the determination of these compounds in the atmosphere.

1976 - Computer model for toxicant spills in Lake Ontario. See under MINNS, C.K.

1976 - CHAU, Y.K., WONG, P.T.S., & SAITOH, H. Determination of tetraalkyl lead compounds in the atmosphere. J.Chromatogr.Sci., 14:162-164.

A gas chromatograph-atomic absorbance (GC-AA) method for the separation and determination of five lead tetraalkyls in air at microgram level is described. It is fast, sensitive and relatively specific. The volatile lead compounds are first collected by a cold trap containing OV-1 at -80°C, swept into the GC, and the effluent is ducted to an AA unit for analysis. At normal AA sensitivity (1X), 0.1 µg of each of the lead alkyls can be determined with certainty.

1976 - LIU, D., & WONG, P.T.S. Bacterial degradation of Bunker 6C fuel oil. In; J.M. MARPLEY & A.M. KAPLAN(eds.), Proc.3rd.Internat. Biodegradation Symposium:175-186. Appl.Sci.Publ.

A bacterium isolated from soil of a local refinery could degrade Bunker 6C oil rapidly. Infrared and gas chromatographic analyses indicated that the major components of Bunker 6C fuel oil contained medium and high molecular weight *n*-alkanes with a relatively small portion of aromatics. The gas chromatographic spectrum also pointed out that the *n*-alkane fractions were the primary target for degradation by the bacterial isolate. Manometric experiments demonstrated that the bacterial culture could oxidize the Bunker 6C oil over a wide range of concentrations.

1977 - with CHAU, Y.K., LUXON, L., & BENGERT, G.A. Methylation of arsenic in the aquatic environment. In; D.D.Hemphill(ed.), Trace Substances in the Environmental Health-XI, 1977. A Symposium: 100-106. Univ.Missouri, Columbia.

Methylated arsenic compounds were detected in a culture in which sediments from various locations in Ontario were incubated with or without the addition of extraneous As. Three pure bacterial cultures grown in a chemically defined medium could also methylate As compounds. The biological generated arsines were - very toxic to alga, *Chlorella pyrenoidosa*. Its primary productivity and cell growth decreased by 45 percent and 44 percent respectively after As exposure.

WONG, P.T.S.(cont.)

A sensitive GC-AAS specially developed for analyzing various As compounds in the culture media, atmosphere and lake water is described.

1977 - with CHAU, Y.K., SILVERBERG, B.A., LUXON, P.L., & BENGERT, G.A. Methylation of selenium in the aquatic environment. Science, 192:1130-1131.

Conversion of inorganic and organic selenium compounds to volatile selenium compounds (dimethyl selenide, dimethyl diselenide, and an unknown compound) by microorganisms in lake sediment has been observed. This conversion could also be affected by pure cultures of bacteria and fungi. Such transformations are significant in the transportation and cycling of elements in the environment.

1977 - SILVERBERG, B.A., WONG, P.T.S., & CHAU, Y.K. Effect of tetramethyl lead on freshwater green algae. Arch.Environm.Contam.Toxicol., 5:305-313.

The toxicity of tetramethyl lead (Me_4Pb) towards freshwater algae was studied by bubbling biologically generated Me_4Pb from one flask containing 5 mg of Pb l^{-1} as Me_3PbOAc into the culture medium in another flask where a test alga Scenedesmus quadricauda was grown. As Me_4Pb is not soluble in water and is volatile, the exposure of an alga to this lead compound was only momentary. It was estimated that less than 0.5 mg of Pb(Me_4Pb) had passed through the culture medium. The primary productivity and cell growth (determined by dry weight), however, decreased by 85 percent and 32 percent respectively, as compared with the controls without exposure to Me_4Pb. Furthermore, cells exposed to Me_4Pb tended to clump together and striking alterations in cell fine-structure were observed. An electron microscopic analysis by an energy dispersive spectrometer revealed that Pb ions had penetrated the cell and were deposited within concretion bodies. Similar results were obtained with the green algae Ankistrodesmus falcatus and Chlorella pyrenoidosa.

1977 - SMITH, E.A., MAYFIELD, C.I., & WONG, P.T.S. Effects of dredged spoils on selected microbial activities in lake column simulators. Wat.Air Soil Pollut., 8:417-428.

Four lake column simulators were filled with hypolimnetic water from Lake Ontario and inoculated with algae and fish. Various microbial processes were monitored before and after the addition of dredged spoils. Loading rates of dredged spoils of 0.33, 3.3 or 33 g day^{-1} were used for each of three columns and one column with no addition of dredged spoils was maintained as a control. The effects of dredged spoils on microbial activities were most pronounced at the highest loading rate. $^{32}P-PO_4$ was rapidly removed from the control water but the presence of suspended particles from dredged material increased both biological assimilation and physical adsorption processes. The influence of dredged spoils on $^{32}P-PO_4$ uptake was most pronounced immediately following loading. Dredged spoils also increased ^{14}C-acetate mineralization in water and the effects were again more pronounced immediately following loading. A 3-fold increase in heterotrophic activity during a 1 h incubation at 20°C was observed following addition of a 33 g day^{-1} loading. Dredged spoils increased the levels of N_2-fixation in the columns as indicated by the C_2H_2-reduction assay procedure. Suspended dredged material reduced light penetration and decreased primary production in the columns. The increased availability of dissolved and particulate organic and inorganic nutrients from continuous addition of dredged spoils was responsible for a general stimulation of microbial activities in the epilimnetic and hypolimnetic regions of the simulated lake columns.

1977 - SMITH, E.A., MAYFIELD, C.I., & WONG, P.T.S. Physical and chemical characterization of selected natural apatites in synthetic and natural aqueous solutions. Wat.Air Soil Pollut., 8:401-415.

Several natural calcium-phosphate apatites, chosen to be representative of the apatite which enters aquatic environments in ground water, runoff and erosion material, were characterized by X-ray diffraction and chemical analyses. Samples were selected to include apatites with widely different structural stabilities and ionic compositions. The solubility of apatite increased as the pH of water and the particle size of apatite crystals were decreased. The concentrations of dissolved ortho-PO_4^{3-} increased in proportion to the amount of apatite added to water and apatite generally increased the pH of water at low slurry densities. The solubility of apatite decreased as the concentrations of ions in water were increased and apatite increased the pH and levels of ortho-PO_4^{3-} in lake water containing relatively high endogenous concentrations of Ca^{2+}, and ortho-PO_4^{3-}.

Increases in soluble ortho-PO_4^{3-} concentrations in limnetic solutions following apatite addition suggest that partial dissolution of apatite crystals can contribute dissolved ortho-PO_4^{3-} to the P-cycle of aquatic ecosystems. The contribution would probable be of significance under oligotrophic conditions, in areas where anthropogenic P loadings are reduced or in regions receiving high inputs of apatite in the form of erosion material.

1977 - SMITH, E.A.H., MAYFIELD, C.I., & WONG, P.T.S. Colonization and decomposition of fish bone material in natural and synthetic aqueous solutions. J.Fish.Res.Bd.Can., 34:2176-2184.

Partial dissolution of the inorganic (apatite) fraction of flesh-free fish (Perca sp) cheek-bone material, added to P-free (<0.001 $\mu g.ml^{-1}$ total P) nutrient media as bone chips with a particle-size distribution of <250 µm, supported considerable populations of algae and bacteria at slightly alkaline pH levels and relatively low slurry densities (1-1000 $\mu g.ml^{-1}$). Bacteria and algae rapidly colonized the apatite bone material and produced extracellular material in response to growth on bone surfaces. Acidic filtrates from bacterial cultures, aerobically or anaerobically cultivated in apatite media, readily solubilized bone material as indicated by increases in soluble ortho-PO_4^{3-}

WONG, P.T.S.(cont.)

concentrations after short exposure periods. Water extraction of bone apatite crystals showed that fish bones are sparingly soluble in lake water. Microbially mediated dissolution of bone material by acid end-products of bacterial metabolism would therefore greatly increase the rate of bone dissolution in nature. Regeneration of allochthonous-P from fish-bone dissolution may contribute significantly to the P-cycle of many aquatic ecosystems.

1977 - SMITH, E.A., MAYFIELD, C.I., & WONG, P.T.S. Effects of phosphorus from apatite on development of freshwater communities. J.Fish. Res.Bd.Can., 34:2405-2409.

Phosphorus-free nutrients were added to three epilimnetic (pH 7.8) 40-L tanks. Apatite crystals (30-100 µm) were added at loading rates of 30, 2, and 0 mg.day^{-1}. After a 60-day incubation at 20°C, levels of particulate organic carbon, particulate nitrogen, and particulate organic phosphorus in Tank 1 increased from 0.42, 0.090, 0.015 to 6.10, 0.820, and 0.430 µg.ml^{-1}, respectively. This increase was due to the proliferation of algae, bacteria, and zooplankton and did not occur in the tank with only P-free nutrients. Algae and bacteria grew extensively on the surfaces of apatite crystals causing crystals to aggregate. Zooplankton increases followed those in algae and bacteria, and grazing was restricted to the areas around the apatite crystals. Results suggest that the contribution of soluble ortho-PO_4^{3-} from apatite to the P-cycle of aquatic environments would be more important under oligotrophic conditions than in areas receiving high loadings of anthropogenic-PO_4^{3-}, particularly where high erosion increases apatite loadings.

1977 - SMITH, E.A.H., MAYFIELD, C.I., WONG, P.T.S., & SILVERBERG, B.A. Effect of naturally occuring apatites on growth and morphology of algae. Can.J.Microbiol., 23:1188-1196.

Crystals (30-100 µm) of selected naturally occuring apatite - $(Ca_{10}(PO4)_6(OHF)_2)$ samples were added to P-free (<0.001 µg/ml total P) Bristol's medium (1-1000 µg/ml of apatite) as the sole source of orth0-PO_4^{3-}. The media were inoculated with washed, non-axenic cells of three chlorophycean algal species cultivated under PO_4^{3-}- deficient conditions. Phase-contrast and scanning electron microscopy revealed that at low slurry densities (1-10 µg/ml of apatite), *Ankistrodesmus braunii* (ATCC 2744) cells were morphologically distorted. At concentrations of 100 and 1000 µg/ml of apatite, more than 85 percent of the cells had undergone autospore formation within 7-10 days of incubation at 20°C. Most autospores formed failed to germinate under high nutrient conditions. *Scenedesmus longus* (No.1236) formed colonies when cultivated in Bristol's medium but daughter cells displayed a *Chodatella*-like unicellular morphology when grown in apatite media. Test algal species (*Chlamydomonas dysosmos, S.longus, A.braunii*) showed a marked preference for growth on apatite crystals over non-nutritive surfaces. Unialgal and mixed-algal cultures produced an extensive matrix of extracellular fibrous material in response to growth on crystals at concentrations greater than 10 µg/ml of apatite.

WONG, P.T.S.(cont.)

1977 - CHAU, Y.K., & WONG, P.T.S. Technical comments on the selenium in the environment. Science, 195:595.

1977 - CHAU, Y.K., SNODGRASS, W.J., & WONG, P.T.S. A sampler for collecting evolved gases from sediment. Wat.Res., 11:807-809.

A simple sampler is described for collecting evolved gases from sediment. It is lightweight, easy to operate and has been successfully applied in studies of the production of methane, carbon dioxide, nitrogen, and oxygen. It is currently being used in studies of the production of volatile organo-metallic compounds, such as $(CH_3)_4Pb$, $(CH_3)_2Se$, $(CH_3)_2Se_2$, and methyl derivatives of arsine from metal-rich sediments.

1977 - CHAU, Y.K., & WONG, P.T.S. An element- and speciation-specific technique for the determination of organometallic compounds. In; G.W.EWING(ed.), Environmental Analysis:215-225. Academic Press, Inc.

The combination of a gas chromatograph and an atomic absorption spectrophotometer provides both a sensitive element- and speciation-specific system for the analyses of low boiling organometallic compounds. The system inherits the separation capability of gas chromatography and the specificity of atomic absorption spectroscopy. The atomic absorption instruments can be operated in either flame or furnace mode. It handles liquid and gaseous samples with detection sensitivity at the subnanogram level expressed as the element. It has been successfully applied to the analyses of several alkylated metallic compounds, such as that of Hg, Pb, Cd, As, Se, Sn, etc., some of which are biologically methylated in the environment.

1977 - CHAU, Y.K., & WONG, P.T.S. An element-specific technique for the analyses of organometallic compounds. U.S.Ntnl.Bur.Stands., Spec.Publ., (464):485-490.

The technique described was primarily developed to study the biological transformation of elements at their environmental concentration levels. This technique utilizes the features of the combination of gas chromatography and atomic absorption spectrometry to provide the capability of separation and specificity for the analyses of low boiling organometallics in gaseous and liquid forms.

1977 - CHAU, Y.K., WONG, P.T.S., & GOULDEN, P.D. A gas chromatograph-atomic absorption spectrophotometer system for the determination of volatile alkyl lead and selenium compounds. Proc.Internat.Conf.Heavy Metals Environm.:295-302.

The combined system of a gas chromatograph and a furnace atomic absorption spectrophotometer is described for the separation, identification and determination of five tetraalkyllead compounds (Me_4Pb, Me_3EtPb, Me_2Et_2Pb, $MeEt_3Pb$, Et_4Pb) and methyl selenides (Me_2Se, Me_2Se_2). The volatile compounds are first collected by a cold trap containing OV-1 at -70°C, swept into the

WONG, P.T.S.(cont.)

GC column, and the effluent is ducted to the silica furnace of the AAS for analysis. The system is highly sensitive, element-specific, and can detect 0.1 ng or lower of Pb and Se.

1978 - with CHAU, Y.K., & LUXON, P.L. Toxicity of a mixture of metals on freshwater algae. J.Fish.Res.Bd.Can., 35:479-481.

Recommended levels of a number of metals for Great Lakes Water Quality Objectives were found to be very toxic to freshwater algae when these metals were present simultaneously in lake water and culture medium. The diatom tested was more sensitive to metal toxicity than the blue-green and green algae.

1978 - with SILVERBERG, B.A., CHAU, Y.K., & HODSON, P.V. Lead and the aquatic biota. In; J.O.NRIAGU(ed.), The Biogeochemistry of Lead in the Environment:279-342. Elsevier Publ.

There is concern today about the possible hazards to living organisms that might result from the widespread dissemination of metals by man into the environment and particularly about the insidious effects of long-term exposure. The purpose of this chapter is; 1) to present data on toxicity and bioaccumulation of lead in aquatic organisms; 2) to illustrate the toxic forms of lead in the aquatic environment and the factors influencing lead toxicity to aquatic organisms; 3) to outline those aspects of the biological effects of lead in an aquatic environment that are of general relevence to an understanding of impacts of organismic physiology in terms of biochemical and cellular damage.

The major groups of organisms that have been studied are algae, macrophytic plants, bacteria, fungi, protozoa, invertebrates, and fish.

1978 - SMITH, E.A., MAYFIELD, C.I., & WONG, P.T.S. Naturally occuring apatite as a source of orthophosphate for growth of bacteria and algae. Microbial Ecol., 4:105-117.

Several naturally occuring calcium-phosphate apatites which varied in crystalline structure and ionic composition were added as crystals of different particle size to P-free (<1 μg/liter total P) nutrient media. Sufficient ortho-PO_4^{3-} was released by the partial dissolution of apatite crystals at limnetic pH levels (pH 7.8) to support growth of several unialgal-mixed bacterial cultures. The biomass produced by mixed populations increased as the amount of available apatite was increased and as the pH of the media and the particle size of the apatite crystals were decreased. These findings suggest that although apatite characteristically displays reduced solubility under alkaline conditions, the tons of apatite which are continuously entering aquatic environments as erosion material may be contributing to the P loading of those ecosystems.

1978 - CHAU, Y.K., & WONG, P.T.S. Biological methylation of elements in the aquatic environment. World Health Organ., Wat.Qual.Bull., (3):8-22.

WONG, P.T.S.(cont.)

Studies on the environmental impacts of biological methylation have gained much momentum since the discovery that microorganisms in a natural lake sediment were able to methylate mercury into a highly-neurotoxic methyl-mercury species. Because methylmercury is produced at a rate faster than organisms can accomplish its degradation, it may accumulate in fish and so poses a threat to public health. Indeed, several cases of mercury poisoning have been documented.

Apart from the increase in toxicity and bioaccumulation of the methylated elements, methylation also plays an important role in the aquatic transport of elements from sediment to water. Attempts have been made to predict the possibility of methylation of other elements. The metals Hg, Sn, Pd, Pt, Au, and Ti, and metalloids As, Se, Te, and S have been postulated to accept methyl groups from methyl-cobalamin in biological systems. However, Pb, Cd, and Zn have been predicted not to be methylated because of the extreme instability of their monoalkyl derivatives in aqueous systems. This paper summarizes the major current research work and findings in this area.

1978 - LIU, D., & WONG, P.T.S. Correlation between carbohydrate and some heterotrophic bacteria in Lake Erie sediments. Can.Res., 11:29-39.

Simultaneous measurements of carbohydrate-utilizing bacteria, total carbohydrate concentration and the rate of oxygen consumption in Lake Erie sediment cores indicate the existence of a close relationship between bacterial populations and the availability of organic nutrients. The decrease of carbohydrate concentration with sediment depth was found to correspond with a decrease in bacterial density and a decrease in rate of oxygen consumption, which implies in situ decomposition of organic nutrients by bacterial activity in sediment.

1979 - CHAU, Y.K., WONG, P.T.S., BENGERT, G.A., & KRAMAR, O. Determination of tetraalkyllead compounds in water, sediment, and fish samples. Analyt.Chem., 51:186-188.

A simple and rapid extraction procedure to extract five tetraalkyllead compounds (Me_4Pb, Me_3EtPb, Me_2Et_2Pb, $MeEt_3Pb$, and Et_4Pb) from water, sediment, and fish samples is described. The extracted compounds are analyzed in their authentic forms by a gas chromatograph-atomic adsorption spectrometry system. Other forms of inorganic and organic lead do not interfere. The detection limits for water (200 ml), sediment (5 g), and fish (2 g) are 0.50 µg/L, 0.01 µg/g, and 0.025 µg/g, respectively. The methods were developed to investigate the occurence of these compounds in environmental samples. Experiments have established that tetramethyllead can be accumulated by fish and remains in its authentic form for some time.

1979 - with CHAU, Y.K. Methylation and toxicity of lead in the aquatic environment. Proc.Internat.Conf.Managem.Control Heavy Metals Environm,, London, U.K., Sept .18-21, 1979:131-134. CEP Consultants, Edinburgh.

WONG, P.T.S.(cont.)

Indigenous microorganisms in certain aquatic sediments were able to methylate several organic Pb(IV) and inorganic Pb(II) compounds to volatile and extremely toxic tetramethyllead. The methylation of organo-Pb(IV) compounds occurs readily with and without the sediment, but that of Pb(II) was sporadic. Several bacterial species isolated from lake water were also able to methylate trimethyllead salts, but not Pb(II) salts, to tetramethyllead in the chemically-defined media.

Methylation also increases the toxicity of lead. Several freshwater algal species after exposure to 0.5 mg of Me_4Pb lost 8S percent of their primary productivity and 32 percent in cell number as compared to controls. Fish after exposure to Me_4Pb accumulated high levels of this compound in their organs with the highest level in the intestine, followed by gills, skin & fillet.

1979 - with BURNISON, G., & CHAU, Y.K. Cadmium toxicity to freshwater algae. Bull.Environm.Contam.Toxicol., 23:487-496.

Data is presented to demonstrate that the degree of Cd toxicity to freshwater algae depends on the indicators used for measuring the effects and the algal species selected for the bioassay.

1979 - with CHAU, Y.K., LUXON, P.L., & SILVERBERG, B.A. Microbial methylation of lead compounds in the aquatic environment. Proc.Can. Soc.Microbiol., 29:44. (Abstract).

1979 - with HODSON, P.V., NIIMI, A.J., CAIRNS, V., & BORGMANN, U. (Eds.). Proceedings of the Fifth Annual Aquatic Toxicity Workshop, November 7-9, 1978, Hamilton, Ontario. Can.Dept.Fish.Environm. Fish.Mar.Serv., Techn.Rept., (862).

These proceedings consist of 26 papers, 6 abstracts, a list of aquatic toxicity research programs in Canada, and discussions from 3 workshop sessions.

Topics covered by the papers include environmental laws, waste treatment effects on toxicity, water quality objectives, acid deposition problems, and state of the art for acute and sublethal toxicity testing. In addition, papers presented in the three concurrent workshops dealt with new techniques in toxicology, biochemical methods for toxicity evaluation and the use of invertebrates in toxicity. Synopses of the workshop sessions summarized by the session chairmen are included. Finally, various aquatic toxicity research programs across Canada are provided.

1979 - VAN DEN BERG, C.M.G., WONG, P.T.S., & CHAU, Y.K. Measurement of complexing materials excreted from algae and their ability to ameliorate copper toxicity. J.Fish.Res.Bd.Can., 36:901-905.

The complexing capacities of three algal exudates and the conditional stability constants of their copper complexes have been determined by an ion exchange method. Their ability to ameliorate copper toxicity towards the primary production of *Chlorella vulgaris* is related to the conditional stability constants, which regulate the ionic copper concentration. *Anabaena cylindrica*, *Navicula*

WONG, P.T.S.(cont.)

pelliculosa, and Scenedesmus quadricauda excreted 6.73, 2.86, and 0.66 µmol/L of complexing ligands, respectively, with conditional stability constants of $10^{7.7}$, $10^{8.1}$, and $10^{8.6}$, respectively, for their corresponding copper complexes. When these constants were applied in calculations, a free copper ion concentration of $10^{-10.3}$ mol/L was found in each exudate.

1979 - CHAU, Y.K., & WONG, P.T.S. Occurence of biological methylation of elements in the environment. In; F.E.BRINCKMAN & J.M.BELLAMA (Eds).Organometals and Organometalloids - Occurence and Fate in the Environment:39-53. Amer.Chem.Soc., Symp.Ser., (82).

Experimental results are discussed on the methylation of lead, selenium, and arsenic in sediments from several lakes in Ontario.

1980 - with MAYFIELD, C.I., & CHAU, Y.K. Cadmium toxicity to phytoplankton and microorganisms. A review. In; J.O.NRIAGU(ed.), Cadmium in the Environment. Part 1. Ecological Cycling:571-585. John Wiley & Sons.

Despite the fact that algae and microorganisms are very important in the aquatic food chains, most of the studies on cadmium toxicity have been on fishes and some invertebrates. Not much is known, however, of the effects on algae and microorganisms. The few such studies on cadmium toxicity have usually been carried out at concentrations above the ambient level present in water. It is essential, therefore, that more toxicity experiments be done by exposing these organisms for longer periods of time at lower concentrations so as to detect any sublethal effects of cadmium. The sensitivity of individual organisms to cadmium and the effects of environmental factors such as temperature, pH, complexing capacity, and water hardness are also important areas for more studies. The whole ecosystem approach, using simple food chains either in the laboratory or in the field, should be thoroughly investigated. Additional information in these areas will certainly provide a better understanding of the effects of cadmium on algae and microorganisms and in turn on the whole ecosystem.

1980 - VAN LOON, J.C., CRUZ, R.B., LYE, J., KINRADE, J.D., CHAU, Y.K., & WONG, P.T.S. Determination of total, hexane extractable, volatile and tetraalkyllead in fish, vegetation, sediment, and water samples. Proc.Pittsburg Conf.Analyt.Chem.Appl.Spectroscopy:686. (Abstract).

1980 - AHMAD, I., CHAU, Y.K., WONG, P.T.S., CARTY, A.J., & TAYLOR, L. Chemical alkylation of lead(II) salts to tetraalkyllead(IV) in aqueous solution. Nature, 287(5784):716-717.

Methylation of lead in the environment would have serious consequences for water quality and for the well being of aquatic biota. As there is strong evidence that tetraalkylleads, the end products of lead alkylation, are considerably more toxic than lead (II) compounds, the elevated levels of inorganic lead now present in inland waterways and sediments as a result of industrial and motor

WONG, P.T.S.(cont.)

vehicle emissions will pose a serious environmental hazard if mechanisms exist for the conversion to alkyllead(IV) species in aquatic systems. In the belief that the key to biological Pb(II) methylation lies in methyl transfer to Pb(II) from a carbonium ion donor (for example S-adenosylmethionine), we recently initiated chemical and biological studies on the reactions of CH_3^+ donors with neutral and anionic Pb(II) compounds. We describe here the unequivocal synthesis of volatile tetramethyllead and other tetraalkylleads from Pb(II) salts and simple chemical reagents in aqueous solution. The known occurence of methyl iodide in natural waters and our demonstration that Me_4Pb is readily synthesized from this reagent and Pb(II) salts in aqueous solution could have far reaching significance not only for the chemical synthesis of toxic organoleads but also for possible mechanisms of microbiological methylation.

1980 - CHAU, Y.K., & WONG, P.T.S. Biotransformation and toxicity of lead in the aquatic environment. In; M.BRANICA & Z.KONRAD(eds.), Lead in the Marine Environment:225-231. Pergamon Press.

Volatile tetramethyllead was detected in culture flasks in which sediments from various locations in Ontario were incubated with and without the addition of extraneous organic and inorganic lead compounds. Under optimum laboratory conditions, the maximum rate for the conversion was ca. 6 percent of the lead at 20°C. The conversion rate was lower at lower temperatures. Several pure bacterial cultures were found to methylate trimethyllead acetate but not inorganic lead to Me_4Pb. Chemical disproportionation reactions of Me_3PbOAc to Me_4Pb accounted for ca. 15-20 percent as compared with the biological reactions. Me_4Pb was much toxic to several algae than organic and inorganic lead compounds.

1980 - CHAU, Y.K., WONG, P.T.S., & GOULDEN, P.D. A sensitive technique for the analysis of tetraalkyllead compounds. In; M.BRANICA & Z.KONRAD(eds.), Lead in the Marine Environment:77-81. Pergamon Press.

The gas chromatograph-atomic absorption system provides a sensitive, element- and speciation-specific technique for the analysis of tetraalkyllead compounds in gaseous and liquid samples, The system inherits the separation capability of gas chromatography and the specificity of element detection of atomic absorption. The atomic absorption instrument can be operated in either the flame or the furnace mode with detection sensitivity at the subnanogram level expressed as the element. It has been applied to the analysis of tetramethyllead in the headspace of biological systems to study biological methylation of lead.

1980 - CHAU, Y.K., WONG, P.T.S., KRAMAR, O., BENGERT, G.A., CRUZ, R.B., KINRADE, J.O., LYE, J., & VAN LOON, J.C. Occurence of tetraalkyllead compounds in the aquatic environment. Bull.Environm. Contam.Toxicol., 24:265-269.

The findings of this investigation are: 1) there was no relationship between species and size of fish and concentration of

WONG, P.T.S.(cont.)

tetraalkyllead; 2) tetraalkyllead was found in fish from various lakes and rivers in Ontario; 3) the type of tetraalkyllead varied in different locations, e.g., in Ganaraska River, trimethylethyllead; in the Bay of Quinte and Lake St.Clair, dimethyldiethyllead and tetraethyllead were found. The reasons for the presence of certain specific alkyllead in fish are not known and are being investigated; 4) in general the concentration of tetraalkyllead is low, representing less than 10 percent of the total lead; 5) the values of volatile lead which should include tetraalkyllead are generally higher than that of tetraalkyllead. However, in some determinations, the values for tetraalkyllead are higher. Problems of sample homogeneity were probably the cause.

1981 - with CHAU, Y.K., KRAMAR, O. & BENGERT, G.A. Accumulation and depuration of tetramethyllead by rainbow trout. Wat.Res., 15:621-625.

Tetramethyllead was found very toxic especially to juvenile rainbow trout (Salmo gairdneri). It was accumulated rapidly from the water by the fish and the highest concentration was found in the lipid layer of the intestine. Depuration of Me_4Pb from the fish organs was initially quite rapid, followed by a slower decrease and eventually reaching residual levels. Environmental concentrations of Me_4Pb detected in the fishery products thus represent a balance between uptake and depuration of this compound in fish.

In conjunction with this study, a dosing system for exposing rainbow trout to Me_4Pb was developed.

1981 - BAKER, M.D., WONG, P.T.S., CHAU, Y.K., MAYFIELD, C.I., & INNISS, W.E. Methylation of lead, mercury, arsenic and selenium in the acidic aquatic environment. Proc.Internat.Conf.Heavy Metals Environm. :645-648. Amsterdam, 1981.

The effect of pH on the methylation of lead, mercury, arsenic and selenium was examined. The study showed that pH affected the methylation of the elements in lake sediment in different ways. The formation of tetramethyllead from trimethyllead acetate increased with increasing pH and proceeded through both biological and chemical methylation mechanisms. Methyl mercury was formed from inorganic mercuric chloride only in the pH range of 5.5 to 6.5. Dimethyl mercury was not detected. Arsenic methylation was enhanced below pH 5.5, but occured over the pH range of 3.5 to 7.5. The levels of methylated selenium compounds were low at pH 3.5, and generally, increasing pH favoured the methylation of selenium.

1981 - CHAU, Y.K., & WONG, P.T.S. Some environmental aspects of organo-arsenic, lead, and tin. In; F.E.BRINCKMAN & R.H.FISH(eds.), Environmental Speciation and Monitoring Needs for Trace Metal-Containing Substances from Energy-Related Processes:68-80. U.S.Dept.Comm., Ntnl.Bur.Stds.

Organometals and organometalloids such as alkylleads, alkyltins, organoarsenics have been found in environmental samples. Apart from anthropogenic sources, amazingly, some of these compounds are

WONG, P.T.S.(cont.)

synthesized by biotic and abiotic processes under environmental conditions. These compounds also undergo complex chemical and biological interactions including, for example, methylation, transmethylation, hydrolysis, photolysis, degradation, etc. For these studies, speciation identification and analysis are prerequisites. The toxicity of organometals towards aquatic biota is closely related to the nature of the organic groups. Generally, toxicity increases with increasing carbon chain length, and also with the degree of alkylation on the metal nucleus. The possibility of using octanol-water partition coefficients of a number of alkyltin compounds to predict toxicity is discussed.

1981 - CHAU, Y.K., WONG, P.T.S., CARTY, A.J., & TAYLOR, L. Evidence for the chemical methylation of lead(II) and Tin(II) in aqueous solution. Proc.10th.Internat.Congr.Organo-Metallic Chem.,, Toronto, Aug.1981:300 (Abstract).

1981 - CHAU, Y.K., WONG, P.T.S., KRAMAR, O., & BENGERT, G.A. Methylation of tin in the aquatic environment. Proc.Internat.Conf.Heavy Metals Environm. :641-644. Amsterdam, 1981.

Incubation experiments with various tin compounds and lake sediments were carried out to study tin methylation under environmental conditions. Results indicated that sediments enriched with inorganic Sn(II) and Sn(IV) produced different methyltin compounds. The transformation of methyltin(IV) compounds occured much more readily than that of inorganic Sn(II) and Sn(IV). In all experiments, Me_4Sn was seldom produced except in the case of Me_3SnCl addition. In a parallel study, chemical methylation experiments indicated that CH_3I could methylate Sn(II) in aqueous medium to $MeSn^{3+}$ and small amounts of Me_2- and Me_3- substituted tin through the oxidative addition route. Sn(IV) compounds did not react with CH_3I.

1982 - with CHAU, Y.K., & PATEL, D. Physiological and biochemical responses of several freshwater algae to a mixture of metals. Chemosphere, 11(4):367-376.

A mixture of 10 metals (As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Se, and Zn) at the Great Lakes Water Objective levels was found to reduce the primary productivity of four cultured freshwater algae (Scenedesmus, Chlorella, Anabaena, and Navicula) as well as natural phytoplankton from Lake Ontario water. The metal mixture also caused a reduction in the reproduction and transport of an amino acid analogue (α-aminoisobutyric acid) by Ankistrodesmus. The depuration and exchange of the amino acid analogue were not affected by the metal mixture. The nitrogenase activity of Anabaena was, however, reduced in the presence of the metal mixture.

1982 - with CHAU, Y.K., KRAMAR, O., & BENGERT, G.A. Structure-toxicity relationship of tin compounds on algae. Can.J.Fish.Aquat.Sci., 39:483-488.

WONG, P.T.S.(cont.)

The effects of a number of inorganic and organic tin compounds on pure cultures of green and blue-green algae and natural phytoplankton in lake water were tested. Organic tin compounds were generally more inhibitory to primary production and reproduction of the algae than inorganic tin compounds. The toxicity of organotin compounds varied considerably with the number and nature of the organic groups attached to tin, with trialkyl tin compounds being the most toxic forms. Within a given alkyl tin compound series, the longer the carbon chain, the higher the toxicity. A direct relationship between toxicity and partition coefficients of trialkyl tin compounds was observed. Other tin compounds had no such direct relationship.

1982 - MAGUIRE, R.J., CHAU, Y.K., BENGERT, G.A., HALE, E.J., WONG, P.T.S., & KRAMAR, O. Occurence of organotin compounds in Ontario lakes and rivers. Environm.Sci.Technol., 16:698-702.

The presence of butyltin and methyltin species is reported for the first time in lakes, rivers, and harbors in Ontario. Concentrations of tri-n-butyltin in Collingwood Harbor, a marina in Lake St.Clair, Toronto Harbor, and Ramsey Lake are 15-60 percent of the LC_{100}^{12d} value for a sensitive aquatic species, rainbow trout yolk sac fry. The species Bu_3Sn^+, Bu_2Sn^{2+}, and inorganic tin are concentrated by factors of up to 10^4 in the surface microlayer relative to subsurface water. Concentrations of methyltin and dimethyltin are high in Kingston Harbor and Whitby Harbor and in industrial areas such as Lake St.Clair.

1982 - BAKER, M.D., INNISS, W.E., MAYFIELD, C.I., & WONG, P.T.S. Effect of pH on the growth and activity of heterotrophic sediment microorganisms. Chemosphere, 11:973-983.

Low pH markedly reduced heterotrophic microbial activity in sediment-lake water systems. A marked reduction in both the rate and the total amount of oxygen consumed occured as pH decreased. In addition, low pH and also low temperature (0^oC) resulted in longer turnover times (Tn) and also smaller V_{max} values when the kinetics of ^{14}C-glucose, ^{14}C-glycine, and ^{14}C-glutamic acid utilization were examined. When the response of the microorganisms to heavy metals was examined, mercury was generally more toxic than lead over the pH range of 4.5 to 7.5 but both metals were more toxic at pH 4.5 than at higher pH levels. Mercury also inhibited oxygen utilization and ^{14}C-glucose mineralization more than lead at all pH levels. Bisulfite reduced microbial activity at all pH levels although it was always more toxic to the sediment microorganisms at pH values of 4 and 5 than at pH 7.

1982 - CHAU, Y.K., WONG, P.T.S., & BENGERT, G.A. Determination of methyltin(IV) and tin(IV) species in water by gas chromatography/ atomic absorption spectrophotometry. Anal.Chem., 54:246-249.

The highly polar and solvated methyltin, dimethyltin, trimethyltin, and Sn(IV) species are extracted into benzene containing tropolone from water saturated with sodium chloride. These compounds are

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butylated in the extract to the tetramethylbutyltins, Me_nSnBu_{4-n} which have sufficient volatility to be separated and analyzed by the GC-AAS system. Large volumes of water sample can be handled. Under normal laboratory conditions, detection limit of 0.04 µg/L can be achieved with 5 L of water sample. Absolute detection limit of the GC-AAS for Sn is 0.1 ng. Volatile organotin compounds such as Me_4Sn and methyltin hydrides can also be analyzed by this method.

1983 - with CHAU, Y.K., & PATEL, D. Comparison of algal bioassay techniques in toxicity studies. Can.Techn.Rept.Fish.Aquat.Sci., (1151):210. (Abstract).

1983 - CHAU, Y.K., & WONG, P.T.S. Direct speciation analysis of molecular and ionic organometals. In; G.G.LEPPARD(ed.), Trace Element Speciation in Surface Waters and its Ecological Implications:87-103. Plenum Press. ISBN 0-306-41269-1.

This paper discusses the capabilities and limitations of the two most basic and popular systems, GC-AAS and LC-AAS, and reviews recent developments. A comprehensive literature review on these topics up to 1977 is referred to.

1983 - BAKER, M.D., INNISS, W.E., MAYFIELD, C.I., & WONG, P.T.S. Effect of acidification, metals and metalloids on sediment microorganisms. Wat.Res., 17(8):925-930.

The mineralization of (^{14}C)glucose was reduced in sediments at pH 4 and 5 compared to pH 7. A large reduction in glucose mineralization was also observed at low temperature (0°C). The majority of bacterial isolates recovered at incubation temperatures Of 0 and 20°C were psychotrophic and the majority of both populations was resistent to lead and selenium while a smaller proportion was resistent to mercury and arsenic. Many of the bacteria were resistent to more than one of the elements. Lead and mercury were more toxic to bacterial growth at pH 4.5 than at 7.5, while selenium and arsenic were slightly more toxic at the higher pH values.

1983 - BAKER, M.D., MAYFIELD, C.I., INNISS, W.E., & WONG, P.T.S. Toxicity of pH, heavy metals and bisulfite to a freshwater green alga. Chemosphere, 12(1):35-44.

Low pH markedly reduced the growth and photosynthetic activity of an Ankistrodesmus sp. The alga could not grow at pH 3 and only slight growth occured at pH 4. The alga grew well above pH 4 with maximum growth occuring at pH 6. The fixation of $^{14}CO_2$ followed a similar pattern with pH. The algal cells were also sensitive to mercury and bisulfite in acidic conditions. Algal growth and photosynthesis were reduced by mercury and bisulfite more at pH 5 than at pH 7. Lead was relatively non-toxic to the algal cells at both pH levels. Bisulfite inhibited the membrane transport of α-amino-^{14}C-isobutyric acid at pH 5 but not at pH 7. The results suggest that algal growth and activity may be reduced in acidic lakes by low pH and that the toxicity of mercury and bisulfite is enhanced in acidic conditions.

1983 - BAKER, M.D., WONG, P.T.S., INNISS, W.E., & MAYFIELD, C.I. Microbial activity in sediments from acidic Ontario lakes. Can.Techn.Rept. Fish.Aquat.Sci., (1151):1-11.

The microbial activity in sediments from three acidic Ontario lakes was examined. The sediment of Big Turkey Lake was pH 6.2, while Plastic Lake and Little Turkey Lake had sediment pH values of 5.8 and 5.7, respectively. These two lake sediments also had slightly higher organic matter and carbohydrate contents. On a comparative basis, the sediment of Plastic Lake contained the lowest number of aerobic, heterotrophic bacteria. Measurements of microbial activity suggested that the microorganisms in the Plastic Lake and Little Turkey Lake sediments were less active than those in the Big Turkey Lake sediment.

Studies were conducted to determine the effect of pH on the microbial activity in the Plastic Lake sediment. The results revealed that both oxygen uptake and the mineralization of various organic substrates were reduced in acidic conditions.

1983 - BAKER, M.D., INNISS, W.E., MAYFIELD, C.I., WONG, P.T.S., & CHAU, Y.K. Effect of pH on the methylation of mercury and arsenic by sediment microorganisms. Environm.Technol.Lett., 4(2):89-100.

The effect of pH on the methylation of mercury and arsenic in lake sediment amended with nutrients was examined. The formation of methyl mercury from inorganic mercuric chloride occured only in the pH range of 5.5-6.5. Dimethyl mercury was not produced. Mercury methylation in this narrow pH range was probably the result of a microbial population which had adapted to the in situ pH of 5.8. The levels of methyl mercury were reduced in the presence of sulfuric acid, probably due to sulfide formation. In the arsenic methylation experiments, volatile arsine or methyl arsines were rarely detected. Analysis of the culture fluid revealed that methyl arsonic acid and dimethyl arsinic acid were formed over the pH range of 3.5 to 7.5. In contrast to the mercury methylation experiments, the arsenic methylating microorganisms were not as sensitive to changes in pH and different microorganisms may have been responsible for methylating arsenic over this pH range.

1983 - BAKER, M.D., WONG, P.T.S., CHAU, Y.K., MAYFIELD, C.I., & INNISS, W.E. Methylation of arsenic by freshwater green algae. Can.J. Fish.Aquat.Sci., 40:1254-1257.

Isolates from four genera of freshwater green algae were capable of methylating sodium arsenite in lake water and Bold's basal medium. Analysis of the liquid phase of the methylation flasks revealed the presence of methylarsonic acid, dimethylarsinic acid, and trimethylarsine oxide. Volatile arsine and methylarsines were not detected in the headspace gases presumably because of the inability of the algae to reduce completely the methylated-arsenic species. Although the algae varied with respect to their methylating abilities, the levels of methylated-arsenic compounds were always significantly higher when the algae were grown in lake water. This may have been due to the lower phosphate concentration in the lake

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water. We suggest that arsenic methylation by green algae constitutes an additional source for the formation and cycling of organic-arsenic compounds in freshwater ecosystems.

1983 - CHAU, Y.K., WONG, P.T.S., & KRAMAR, O. The determination of dialkyllead, trialkyllead, tetraalkyllead and lead(II) ions in water by chelation/extraction and gas chromatography/atomic absorption spectrometry. Anal.Chim.Acta, 146:211-217.

The highly polar and solvated dialkyllead, trialkyllead and lead(II) ions are quantitatively extracted into benzene from aqueous solution after chelation with dithiocarbamate. The lead species are butylated by Grignard reagent to the tetraalkyl form $R_nPbBu_{(4-n)}$ ($R = CH_3$ or C_2H_5) and Bu_4Pb, all of which can be quantified by a gas chromatography-atomic absorption spectrometry method. Molecular covalent tetraalkyllead species, if present in the sample, are also extracted and quantified simultaneously. A detection limit of 0.1 g l^{-1} lead can be achieved with one litre of water. Other metals co-extracted by the chelating agent do not interfere.

1983 - with CHAU, Y.K., & PATEL, D. The use of algal batch and continuous culture techniques in metal toxicity studies. In; J.O.NRIAGU(ed.), Aquatic Toxicology:450-466. John Wiley & Sons, Inc.

Five techniques were used to study the effects of a mixture of 10 metals at the recommended Great Lakes Water Quality Objectives levels on a freshwater green alga, *Ankistrodesmus falcatus*. The first three techniques involved batch culture and the other two were continuous culture techniques. The batch culture techniques included $^{14}C-NaHCO_3$ uptake, cell count, and optical measurement of cell growth. The continuous culture techniques involved a turbidostat and a chemostat. There were advantages and disadvantages of each of these five techniques in algal bioassays. However, the results from these techniques all indicated that the metal mixture was toxic to the green alga.

1984 - with CHAU, Y.K. Structure-toxicity of triaryl phosphates in freshwater algae. Sci.Total Environm., 32:157-165.

The effects of six triaryl phosphate compounds on the primary productivity of pure algal cultures and natural phytoplankton in lake water were tested. Substitution of the hydrogen atom by a methyl group in the benzene ring decreased its effect. Triphenyl phosphate was the most toxic compound, followed by tolyl diphenyl phosphate, tritolyl phosphate and trixylyl phosphate. The *ortho*-isomer of tritolyl phosphate was more toxic than the *meta*- and *para*- isomers. Natural phytoplankton was more sensitive to triaryl phosphate compounds than the pure algal cultures. In addition to the primary productivity, the reproduction and nitrogenase activity of the algae were also reduced in the presence of triphenyl phosphate.

1984 - with CHAU, Y.K., RHAMEY, J.S., & DOCKER, M. Relationship between water solubility of chlorobenzenes and their effects on a freshwater green alga. Chemosphere, 13(9):991-996.

WONG, P.T.S.(cont.)

The effective concentrations of benzene and 12 chlorobenzenes that reduced 50 percent of the primary productivity (EC_{50}) of a freshwater green alga, Ankistrodesmus falcatus, were determined. Benzene was the least toxic chemical and the toxicity increased as the degree of chlorine substitution in the aromatic ring increased. No EC_{50} value could be obtained for HCB. A quantitative relationship was found to exist between water solubility, lipophilicity and the EC_{50}. A good correlation was also observed between the EC_{50} for this alga and other toxicity data for various aquatic biota.

1984 - with MAGUIRE, R.J., CHAU, Y.K., & KRAMAR, O. Uptake and accumulation of inorganic tin by a freshwater alga, Ankistrodesmus falcatus. Can.J.Fish.Aquat.Sci., 41:1570-1574.

Uptake of Sn by Ankistrodesmus falcatus occured very rapidly. The alga accumulated 2.3 and 4.1 mg Sn/g dry weight of cells after 2 and 60 min of incubation, respectively, in the presence of 46 µg Sn/L of medium. Increasing Sn concentrations in the medium resulted in a steady increase in the Sn concentrations in the cells. At 6 mg of Sn and 3 mg of dry weight of cells in 1 L of medium, the cells had accumulated 100 mg Sn/g dry weight of cells, representing 10 percent of the dry cell mass. The uptake of Sn from the medium and the release of Sn from the cells were not affected by other metals (Pb, As, Zn, Cd, Hg, Sb, and Cu). Addition of EDTA, however, caused an immediate and rapid release of 60 percent of Sn from the cells. Heat-killed cells took up Sn faster and to a higher level than living nonheated cells. About 85 percent of Sn taken up by the cells was recovered in the cellular polysaccharide fraction and 15 percent in the protein fraction, while the lipid and the small molecular weight metabolites accounted for 0.2 percent of the total Sn.

1984 - CHAU, Y.K., & WONG, P.T.S. Organic lead in the aquatic environment. In; P.GRANDJEAN & E.C.GRANDJEAN(eds.), Biological Effects of Organolead Compounds:21-31. CRC Press. ISBN 0-8493-5309-2.

It is concluded that: 1) The GC-AAS method is the most versatile and sensitive for specifically identifying and determining alkyllead compounds in aquatic and biological samples; 2) no significant concentration of alkyllead has so far been found in natural waters except in areas of contamination; 3) a variety of biological samples has been found to contain elevated levels of alkyllead compounds; 4) in general, Et_4Pb is the most toxic alkyllead compound. R_3Pb^+ is less toxic than R_4Pb. Fish are most sensitive while bacteria are most resistant to alkyllead toxicity.

1984 - MAGUIRE, R.J., WONG, P.T.S., & RHAMEY, J.S. Accumulation and metabolism of tri-n-butyltin cation by a green alga, Ankistrodesmus falcatus. Can.J.Fish.Aquat.Sci., 41:537-540.

Tributyltin pesticides are increasingly widespread, but their environmental persistence is poorly known. The accumulation and metabolism of tri-n-butyltin cation (Bu_3Sn^+) by a green alga, Ankistrodesmus falcatus, was determined at 20°C over a 4-wk period;

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about 50 percent of the original Bu_3Sn^+ was converted to di-n-butyltin (Bu_2Sn^{2+},) and small quantities of butyltin ($BuSn^{3+}$) and inorganic tin. An apparent algal concentration factor of 3×10^4 was estimated for Bu_3Sn^+.

1984 - Lead contamination of the Great Lakes and its potential effects on aquatic biota. See under HODSON, P.V.

1984 - CHAU, Y.K., WONG, P.T.S., BENGERT, G.A., & DUNN, J.L. Determination of dialkyllead, trialkyllead, tetraalkyllead and lead(II) compounds in sediment and biological samples. Anal.Chem., 56:271-274.

A tissue solubilizer is used to dissolve biological samples without altering the chemical forms of the alkyllead species. The various alkyllead species and lead(II) are isolated quantitatively by chelation extraction with sodium diethyldithiocarbamate, followed by n-butylation to their corresponding tetraalkyl forms, $R_nPbBu_{(4-n)}$, and Bu_4Pb respectively (R = Me, Et), all of which can be determined by a GC/AAS method. The method determines simultaneously the following species in one sample: tetraalkyllead (Me_4Pb, Me_3EtPb, Me_2ET_2Pb, $MeEt_2Pb^+$); ionic alkyllead (Me_2Pb^{2+}, Et_2Pb^{2+}, Me_3Pb^+, El_3Pb^+); Pb^{2+}. Analysis of sediment, fish, and aquatic weeds are given. Detection limits expressed for Pb are 7.5 ng/g and 15 ng/g, respectively, for biological and sediment samples.

1984 - CHAU, Y.K., MAGUIRE, R.J., WONG, P.T.S., GLEN, B.A., BENGERT, G.A., & TKACZ, R.J. Occurence of methyltin and butyltin species in environmental samples in Ontario. Can.Dept.Environm., Ntnl.Wat.Res.Inst., Unpubl.Rept.Ser., (84-01).

During fiscal years 1982-1983 and 1983-1984 the Great Lakes Water Quality Program provided funding for a survey to determine the extent of contamination of waters on the Canadian side of the Great Lakes basin by methyltin and butyltin compounds. This is the report of the results of analyses of water, sediment and fish from about 100 locations, largely in Ontario. Butyltin species were widely found in water and sediment samples. The highest concentrations were in harbours, reflecting the use of tri-n-butyltin as an antifouling agent in boat paint. Methyltin species were infrequently detected, and their occurence was correlated with the presence of relatively high concentrations of inorganic tin.

1985 - CHAU, Y.K., MAGUIRE, R.J., WONG, P.T.S., & SANDERSON, M.E. (Spec.eds.), Detroit River-St.Clair River Special Issue. J.Great Lakes Res., 11(3).

The papers in this Special Issue present some of the most recent results of scientific investigations. They deal with a variety of biogeochemical research results which help to identify and assess pollution issues in the Upper Great Lakes connecting channels and in the adjacent parts of Lakes Huron and Erie. The purpose of the volume is to describe sources and begin to develop an understanding

WONG, P.T.S.(cont.)

of the aquatic pathways of the contaminants, including exposure to and effects on aquatic biota and human populations.

1985 - CHAU, Y.K., WONG, P.T.S., BENGERT, C.A., DUNN, J.L., & GLEN, B. Occurence of alkyllead compounds in the Detroit and St.Clair Rivers. J.Great Lakes Res., 11(3):313-319.

Environmental occurence of alkyllead compounds, both of molecular species, e.g., tetraalkyllead, and ionic species, e.g., dialkyllead and trialkyllead, is believed to be derived mainly from anthropogenic sources such as effluents of alkyllead production plants and from slow degradation of tetraalkyllead in the environment. The present study describes a survey for the occurence of tetraalkyllead, trialkyllead, dialkyllead, and Pb(II) (R = Me 'Et) in water, surface microlayer, fish, and sediments from 29 stations in the St.Clair and Detroit Rivers, including the westend basin of Lake Erie. Results indicated that triethyllead and diethyllead compounds have been found for the first time in fish and surface microlayer in St.Clair River near Corruna where a production plant is located. About 48 percent of the surface microlayer samples contained various alkyllead compounds whereas only one water sample taken from the St.Clair River was found to contain alkyllead. Alkyllead compounds were found in several species of fish caught in the St.Clair River, with northern pike containing the highest concentration of alkyllead (0.173 µg/g) followed by white sucker, carp, and walleye. The concentrations of alkyllead in some individual fish reached the p.p.m. level which is considered highly hazardous for consumption although health criteria for alkyllead are not yet available. The ratios of alkyllead to total lead ranged from 0 percent for yellow perch and brown trout to 56 percent for carp.

1985 - CHAU, Y.K., & WONG, P.T.S. Group VI organometallics in the environment. In; P.J.CRAIG(ed.), Organometallics in the Environment:254-278. Longman Publ., London.

Organo Group VI compounds are not widely used industrially and commercially as compared with other organometals, such as tin and lead. Because of their limited usage, environmental contamination is not a serious problem. However, inorganic sulphur compounds are implicated in causing acid precipitation. Environmental occurence of organic selenium and tellurium compounds is still not well established due to lack of suitable analytical methodology. Biomethylation of selenium and tellurium has been well documented. However, there is still no mechanistic evidence to substantiate biomethylation of inorganic sulphur compounds, but of course methyl compounds do occur. Environmental toxicological information of organo Group VI elements is extremely limited. No systematic or quantitative studies have been carried out, and further research should be addressed to the above areas.

1986 - with COUTURE, P. Toxicity screening using phytoplankton. In; B.J.DUKTA & G.BITTON(eds.), Toxicity Testing Using Microorganisms. Volume II:79-100. CRC Press. ISBN 0-8493-5257-6.

WONG, P.T.S.(cont.)

The physiological and anabolic parameters for use in testing phytoplankton responses to toxicants include cell growth, fluorescence, 14C assimilation enzymes, nucleic acid, adenylate energy charge, etc. Two procedures (cell counts and fluorescence) commonly used for assessing lethal and sublethal effects of toxicants are detailed. It is hoped that these and other methods can be further improved and standardized so that results from different laboratories can be compared with confidence.

1986 - with SHEAR, H., CHAU, Y.K., NALEWAJKO, C., & RHAMEY, S. Ultra-clean techniques in assessing the effects of metals on phytoplankton. Can.Techn.Rept.Fish.Aquat.Sci., (1462):75-94.

The necessity of using ultra-clean 'metal-free techniques in measuring primary productivity in water from Batchewana Bay, Lake Superior and Little Turkey Lake, Ontario, was evaluated. There was no significant difference in productivity in lakewater collected with a Van Dorn bottle (which has metal components) and with a metal-free rubber-and-plastic hand pump; however, incubation in polycarbonate flasks gave much higher values than in glass flasks. The decrease in values in glass flasks may have been due to the leaching of metals from the glass flasks; although there was no detectable difference in the quantity of Cu, Pb or Ni leached from the two types of flasks the values were below the detection limit of our method. The addition of a mixture of metals Cu (5 μg/L), Zn (30 μg/L), Ni (25 μg/L), and Pb (25 μg/L) resulted in a more drastic decrease in productivity in polycarbonate than in glass flasks.

1986 - CHAU, Y.K., & WONG, P.T.S. Organic group VI elements in the environment. In; P.J.CRAIG(ed.), Organometallic Compounds in the Environment. Principles and Reactions:254-278. Longman. ISBN 0-582-46361-0.

1986 - MAGUIRE, R.J., TKACZ, R.J., CHAU, Y.K., BENGERT, G.A., & WONG, P.T.S. Occurence of organotin compounds in water and sediment in Canada. Chemosphere, 15(3) :253-274.

Water and sediment samples from 265 locations across Canada were analyzed for butyltin and methyltin species, and inorganic tin. In 10 percent of the water samples the highly toxic tributyltin species was found at concentrations which could cause growth retardation upon chronic exposure to a sensitive organism, rainbow trout yolk sac fry. High concentrations of tributyltin were found in some sediments (up to 10 mg Sn/kg dry weight), but the biological availability of sediment-associated tributyltin is unknown. Tributyltin was mainly found in areas of heavy boating and shipping traffic, which is consistent with its use as an antifouling agent in some paints for boats, ships, and docks. The methyltin species were found much less frequently in water and sediment than tributyltin and its degradation products.

1986 - CHAU, Y.K., & WONG, P.T.S. Occurrence of molecular and ionic alkyllead compounds in environmental samples. In;J.N.LESTER, R.PERRY, & R.M.STERRITT(eds.), Chemicals in the Environment:72-82. Selper Publ., England.

Alkyllead compounds, both of molecular species, e.g. tetraalkyllead, and ionic species, e.g. trialkyllead and dialkyllead (Me, Et) and Pb(II) have been found in surface microlayer, water, fish, clams, aquatic weeds and sediments in St.Clair and St.Lawrence Rivers near lead alkyls production plants. These compounds are derived from the plant effluents and from degradation of tetraalkyllead. In St.Clair River, highest concentrations of alkyllead species in fish were found in nothern pike (0.17 $\mu g\ g^{-1}$), white sucker, carp and walleye. In St.Lawrence River, highest concentrations were found in redhorse sucker (5.04 $\mu g\ g^{-1}$), followed by white sucker, yellow perch and rock bass. Surface microlayer samples contained much higher concentrations of tetraalkyllead, and ionic alkyllead, e.g. trialkyllead and dialkyllead which were not present in the underlying water. Caged clams placed in these areas concentrated alkyllead compounds mostly in the muscle and viscera tissues.